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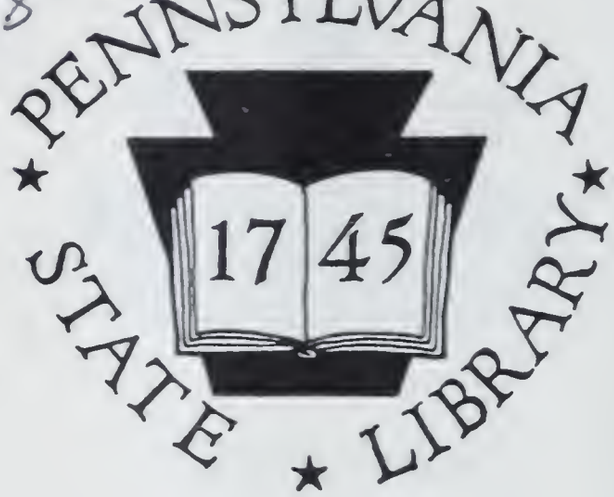

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VOLUME 48

1932

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Published by the Secretary under the direction of the Publication Committee
Published monthly except August and September*
E. H. McClelland, Technical Editor

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CONTENTS

JANUARY

The Sky-Scraper in Its Relation to the Present and Future Elevators. *H. D. James* 1

Architectural Problems of Building Construction. *Alfred Shaw* 13

FEBRUARY

Structural Design. *Frank E. Brown* 31

Foundations. *Carlton S. Proctor* 46

MARCH

Plasticity as Applied to Steel Products. *A. Nadai* 65

APRIL

Recent Gas Developments in Northern Pennsylvania and Southern New York. *J. French Robinson* 81

MAY

Pymatuning Reservoir Project. *Charles E. Ryder* 103

JUNE-JULY

Problems in Steam-Turbine Design. *C. Richard Soderberg* 155

OCTOBER

Machine Control and Regulation of Steam-Boilers. *C. J. King* 189

Electrical System for Metered Control of Boiler Furnaces. *E. S. Bristol* and *B. F. Keene* 203

NOVEMBER-DECEMBER

Automatic Control of Combustion. *H. M. Hammond* 219

Automatic Combustion Control on Steel-Mill Boilers. *T. A. Peebles* and *G. W. Smith* 263

AUTHOR INDEX

Bristol, E. S. 203
Brown, Frank E. 31
Hammond, H. M. 219
James, H. D. 1
Keene, B. F. 203
King, C. J. 189
Nadai, A. 65
Peebles, T. A. 263
Proctor, Carlton S. 46
Robinson, J. French 81
Ryder, Charles E. 103
Shaw, Alfred 13
Smith, G. W. 263
Soderberg, C. Richard 155

GENERAL INDEX

ACKENHEIL, A. C. Discussion of Pymatuning reservoir. 144, 145.
Air conditioning. Factory and office buildings. 19.
Architectural Problems of Building Construction. ALFRED SHAW. 13.
AUSTIN, W. M. Discussion of Pymatuning reservoir. 144.
Automatic Combustion Control on Steel-Mill Boilers. T. A. PEEBLES and G. W. SMITH. 263.
Automatic Control of Combustion. H. M. HAMMOND. 219.
Automatic regulation of boilers. *See* Combustion control.
Automobile parking. *See* Elevator.
"Bakelite". *See* Plasticity.
BÉHAR, M. F. Discussion of Combustion control. 287, 294.
Bibliography. Steam-turbine. 184.
BIGGERT, F. C., JR. Discussion of Plasticity. 78.
BLUM, L. P. Discussion of Pymatuning reservoir. 148.
Boiler regulation. *See* Combustion control.
BONINE, C. A. Discussion of Natural gas. 101.
BOYNTON, A. J. Discussion of Combustion control. 244.
BRISTOL, E. S., and KEENE, B. F. *Electrical System for Metered Control of Boiler Furnaces.* 203.
BROWN, FRANK E. *Structural Design.* 31.
Building construction.
    Architectural features. 13.
    Design. 31.
    Drawings. 16, 36, 42, 45.
    Floor. 35, 36, 39.
    Foundations. *See* Foundation design.
    Materials. 16, 17.
    Type of structure. 34.
    Wind bracing. 38, 41, 45.
    See also Sky-scrapers.
Caisson, Pneumatic. *See* Foundation design.
Canal. *See* Canal project, *under* Pymatuning reservoir.
CHESTER, J. N. Discussion of Pymatuning reservoir. 140, 143, 146.
Chromium plating. *See* Erosion, *under* Steam-turbine.
Combustion control.
    Automatic. 189, 203, 219, 263.
    Electrical. 203, 257, 260, 281, 294, 295.
    Flue-gas. 209.
    Manual. 199, 253, 264.
    Terminology. 288, 292, 293.

Concrete.
Reinforcing rod. Stresses. 78.
Conneaut Lake. *See* Pymatuning reservoir.
CUTLER, D. E. Discussion of Steam-turbine. 186.
Dam. *See* Pymatuning reservoir.
DAVIS, C. S. Discussion of Plasticity. 76, 77, 78.
DICKEY, P. S. Discussion of Combustion control. 256.
Drafting. *See* Drawings, *under* Building construction.
Drawing, Architectural. *See* Drawings, *under* Building construction.
Drawings. *See* Building construction.
DUDLEY, C. L. Discussion of Combustion control. 283.
EGGE, J. J. Discussion of Foundation design. 60.
Electric elevator. *See* Elevator.
Electrical control. *See* Combustion control.
Electrical System for Metered Control of Boiler Furnaces. E. S. BRISTOL and B. F. KEENE. 203.
Elevator.
Automobile parking. 11.
Electric. 1.
Erosion. Turbine blades. *See* Erosion, *under* Steam-turbine.
Escalator. 9.
Flood control. *See* Pymatuning reservoir.
Floor. *See* Building construction.
Flue-gas. *See* Combustion control.
Foundation design. 36, 39, 46.
Pneumatic caisson. 53, 62.
Quicksand. 54.
Selection of type. 52.
Soils. 46, 58, 60, 63.
Foundations. CARLTON S. PROCTOR. 46.
FROCHT, M. M. Discussion of Plasticity. 72.
Furnace. *See* Combustion control.
Gas. *See* Natural gas.
Geology. *See* Natural gas.
Glass. *See* Plasticity.
GRIFFIN, V. P. Discussion of Combustion control. 249.
HAGGART, C. N. Discussion of Building construction. 19.
HAGGART, C. N. Discussion of Elevator. 11.
HAGGART, C. N. Discussion of Foundation design. 59, 63.
HAGGART, C. N. Discussion of Structural design. 44.
HAINES, W. L. R. Discussion of Pymatuning reservoir. 140, 141, 145.
HAMMOND, H. M. *Automatic Control of Combustion.* 219.
HEALD, K. C. Discussion of Natural gas. 99.
History. Pymatuning reservoir. 105.

Illumination. 22.
Natural. 24, 29.
Skylight. 29.
Window shading. 27.
JAMES, H. D. *The Sky-Scraper in Its Relation to the Present and Future Elevators.* 1.
KARPOV, A. V. Discussion of Elevator. 12.
KEENE, B. F., and BRISTOL, E. S. *Electrical System for Metered Control of Boiler Furnaces.* 203.
KING, C. J. Discussion of Combustion control. 260.
KING, C. J. *Machine Control and Regulation of Steam-Boilers.* 189.
KNOWLES, MORRIS. Discussion of Pymatuning reservoir. 146.
Lake Erie and Ohio River Canal. *See* Canal project, *under* Pymatuning reservoir.
LEE, E. B. Discussion of Building construction. 20.
LEERBERG, N. Discussion of Plasticity. 78.
LEHMAN, GEORGE M. Discussion of Pymatuning reservoir. 148.
Lighting. *See* Illumination.
Lubrication. *See* Bearings, *under* Steam-turbine.
Machine Control and Regulation of Steam-Boilers. C. J. KING. 189.
MCNULTY, D. L. Discussion of Combustion control. 292.
MEALS, S. W. Discussion of Natural gas. 99, 101.
MERRILL, F. S. Discussion of Structural design. 44.
MORSE, E. K. Discussion of Pymatuning reservoir. 142, 148.
MYLREA, T. D. Discussion of Structural design. 45.
NADAI, A. *Plasticity as Applied to Steel Products.* 65.
Natural gas.
New York. 81.
Pennsylvania. 81.
Drilling methods. 95.
Well log. 85, 86.
Nitriding. *See* Erosion, *under* Steam-turbine.
Nomenclature. *See* Terminology, *under* Combustion control.
Office building. *See* Building construction. Sky-scrapers.
Paraffin. *See* Plasticity.
PEEBLES, T. A., and SMITH, G. W. *Automatic Combustion Control on Steel-Mill Boilers.* 263.
Pennsylvania. *See* Natural gas.
Photo-elasticity. *See* Plasticity.
Pittsburgh. Foundations.
Keystone Club. 62.
Koppers building. 62.
Post-office. 57.
Y. M. C. A. 62.

Plasticity.
"Bakelite" models. 75.
Glass under stress. 73, 74.
Paraffin. 65, 71.
Steel. 65.
Bar. 76.
Plasticity as Applied to Steel Products. A. NADAI. 65.
Pneumatic caisson. *See* Foundation design.
Power-plant. *See* Combustion control.
PRICE, P. W. Discussion of Pymatuning reservoir. 142.
Problems in Steam-Turbine Design. C. RICHARD SODERBERG. 155.
PROCTOR, CARLTON S. *Foundations.* 46.
PURCELL, T. E. Discussion of Combustion control. 244, 247, 262.
PURCELL, T. E. Discussion of Steam-turbine. 185, 187.
Pymatuning reservoir. 103, 117.
Canal project. 148.
Conneaut Lake. 143, 152.
Dam. 112, 132.
Flood control. 114.
History. *See* History.
Purpose. 108.
Pymatuning swamp. 103.
River regulation. 114.
Sanitation. 111, 146.
Water-power. 112.
Pymatuning Reservoir Project. CHARLES E. RYDER. 103.
Quicksand. *See* Foundation design.
Recent Gas Developments in Northern Pennsylvania and Southern New York. J. FRENCH ROBINSON. 81.
Reinforcing rod. *See* Concrete.
Reservoir. *See* Pymatuning reservoir.
RIEGLER, L. J. Discussion of Building construction. 19.
RIEGLER, L. J. Discussion of Elevator. 11.
River regulation. *See* Pymatuning reservoir.
ROBINSON, J. FRENCH. *Recent Gas Developments in Northern Pennsylvania and Southern New York.* 81.
RYDER, CHARLES E. *Pymatuning Reservoir Project.* 103.
Sanitation. *See* Pymatuning reservoir.
SAURBREY, ALEXIS. Discussion of Foundation design. 60.
Sewage. *See* Sanitation, *under* Pymatuning reservoir.
SHAW, ALFRED. *Architectural Problems of Building Construction.* 13.
SHIRK, W. B. Discussion of Plasticity. 72, 78, 79.
Skylight. *See* Illumination.
Sky-Scraper in Its Relation to the Present and Future Elevators. H. D. JAMES. 1.

Sky-scrapers.
Architecture. 13.
Elevator service. *See* Elevator.
History. 18.
Superintendence of construction. 17, 43.
SMITH, G. W., and PEEBLES, T. A. *Automatic Combustion Control on Steel Mill Boilers.* 263.
SODERBERG, C. RICHARD. *Problems in Steam-Turbine Design.* 155.
Soils. *See* Foundation design.
Stainless steel. *See* Steam-turbine.
Steam-boiler. *See* Combustion control.
Steam-turbine.
Design. 155.
Bearings. 183.
Efficiency. 155, 158.
Erosion. 169, 187.
High temperatures. 163.
Mechanical strength. 159, 173.
Stainless steel. 164.
Stress. 160, 166.
Vibration. 176.
Steel. *See* Plasticity.
Stress. *See* Plasticity. Reinforcing rod, *under* Concrete. Steam-turbine.
Structural Design. FRANK E. BROWN. 31.
STURGES, T. B. Discussion of Foundation design. 63.
TATTERSALL, L. Discussion of Combustion control. 214.
THOMAS, GEORGE W. Discussion of Building construction. 22.
THOMAS, J. E. Discussion of Combustion control. 253.
Turbine. *See* Steam-turbine.
Vertical transportation. *See* Elevator. Escalator
Vibration. *See* Steam-turbine.
Water-power. *See* Pymatuning reservoir.
Water-supply. *See* Sanitation, *under* Pymatuning reservoir.
Well log. *See* Natural gas.
WILHOITE, A. L. Discussion of Combustion control. 247.
Wind bracing. *See* Building construction.
YOUNG, L. E. Discussion of Natural gas. 99.

Vol. 48 JANUARY 1932 No. 1

PROCEEDINGS

OF THE

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

CONTENTS

PAGE

The Sky-Scraper in Its Relation to the Present and Future Elevators. *H. D. James* - - - - - - - - - 1

Architectural Problems of Building Construction. *Alfred Shaw* - 13

Current Publications in the Reading Room - - - - - - vi

Alphabetical Advertising Index - - - - - - - - viii

Classified Advertising Index - - - - - - - - - xix

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PROCEEDINGS OF THE

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Published by the Secretary under the direction of the Meetings and Papers Committee in Pittsburgh, Penna. Published Monthly except August and September.
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University of Illinois. Bulletin
University of Pittsburgh "Business Review"
Water Works and Sewage
Welding
Western Railway Club. Official Proceedings
Western Society of Engineers. Journal
Wisconsin Engineer

ALPHABETICAL LIST OF ADVERTISERS

Baldwin Chain & Manufacturing Co.....xii
Blum, Weldin & Co.....ix

Chester Engineers, J. N.....ix

Diescher & Sons, S.....ix
Duff, Samuel E.....ix
Dnquesne Light Co.....xvii
Duquesne Slag Products Co.....xvi

Eavenson, Alford & Hicks.....ix
Edeburn-Cooper Co.....ix

First National Bank at Pittsburgh.....xiv
Fohl, W. E.....ix

Homestead Valve Manufacturing Co.....xvi
Hunt & Co., Robert W.....ix

Jones & Laughlin Steel Corporation.....xiii

Kennedy, Julian xvi
Koppers Co.....xv

Link-Belt Co..... Front cover

McLean, Harold A.....ix
Morse, E. K.....ix
Moore & Co., W. E.....ix

National Meter Co.....xiii

Phillips Mine & Mill Supply Co.....xv
Pittsburgh Equitable Meter Co.....xvi
Pittsburgh Piping & Equipment Co.....xvi
Pittsburgh Valve, Foundry & Construction Co.....xvi

Rawsthorne Co., Robert.....xviii
Ready Mixed Concrete Co.....xiv
Rust Engineering Co.....xii

Taylor-Wilson Manufacturing Co.....xviii

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For Classified List of Advertisers see page xix

W. E. FOHL
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THE SKY-SCRAPER IN ITS RELATION TO THE PRESENT AND FUTURE ELEVATORS*

By H. D. James†

Electric power has contributed a great deal to the modern sky-scraper; without it, tall buildings would be impractical. Electric power furnishes lighting and ventilation, it operates electrical appliances, and has made the modern elevator possible. Buildings 400 or 500 feet high would have presented difficult problems for the hydraulic elevator. The modern electric elevator handles from 50 to 100 per cent. more passengers in a given time than the manually controlled elevators available 10 years ago.

The outstanding improvement in the electric elevator was the development of the variable voltage system of control. This system makes use of a separate generator for each elevator motor. The speed and direction of travel of the elevator are controlled by changing the strength and direction of the field magnetism in the generator. This gives a smooth and accurate control and has made possible rapid acceleration and deceleration. This control for elevators was attempted 30 years ago, but was not successful due to a lack of proper knowledge of dynamo-electric machines. Experience gained since then in the use of this control for mine hoists, reversing steel-mills and other applications furnished the necessary technical information to apply this system successfully to elevators about 1922. By 1924 it had been adopted by all of the important elevator companies furnishing equipment for large buildings.

This control has made possible automatic landing without additional hoisting equipment. Previous to that time an inaccurate landing was corrected by automatic leveling, which was an improvement on the old system of hand leveling, though time was lost in maneuvering; an auxiliary hoisting equipment was necessary with rheostat control. A step forward was taken when automatic landing stopped the car on a level with the floor and eliminated the previous inaccurate stopping.

The push-button control used for house elevators was developed and combined with the signal system so that each elevator is now

*Presented November 5, 1931. Received for publication November 21, 1931.

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automatically stopped at the desired landing by operating a set of buttons in the car. On entering, the passenger designates his floor and the operator pushes the corresponding button. This causes the car to slow down automatically and stop level with that floor. A person at the upper landing desiring to take an elevator car pushes the "up" or "down" button, which automatically stops the first car approaching that landing in the desired direction. This has relieved the operator of the necessity of stopping the car in response to signals or requests of passengers. When the cars stop, the doors open automatically, so that the only functions now performed by the operator are to initiate the closing of the doors and the starting of the cars.

The automatic doors have been greatly improved with the development of the electric operator. These doors are now opened in about 1½ seconds. The opening is initiated when the car is a few inches from the landing so that the doors are open when the car comes to rest.

We now have the electric eye to guard the opening so that the doors can not be closed while any person is in the opening. Most of the accidents to people occur because the operator has his attention momentarily diverted, and manipulates the doors at the wrong time. The electric eye will never have its attention diverted and will always function in the described manner.

Automatic dispatching has now replaced personal dispatching so that the cars are maintained on a definite schedule by mechanical means, which is far more accurate than personal means. These dispatching systems can be adjusted by the starter when conditions become abnormal, but ordinarily they take care of the situation without attention. When a car is delayed, its place is automatically taken by the next car, which picks up the load and enables the other car to maintain its new schedule.

The operator in the car has become of minor importance and in all probability will be eliminated in the near future. Elimination of the guards on the subway trains, to open and close the entrance doors, and the substitution of automatic means for this purpose have materially improved the service. This problem and the elevator problem are very similar and the latter will probably adopt the same practice.

For over thirty years the speed of passenger elevators seldom exceeded 600 feet a minute. This speed limit was fixed by ordinance

in some cities. Recently elevators are being operated through the express zone at 900 to 1200 feet a minute. New York has at last changed its ordinance removing the 600-foot speed limitation.

Elevator cars are now being equipped with telephones so that persons within the car may communicate with the dispatcher at the entrance level or with the building office in case of need. In the future we may equip these cars with television so that the dispatcher may view the interior of a car and note if it is heavily loaded, or in case of accident know what is the most desirable thing to do.

We have witnessed a definite effort upon the part of railway car builders to reduce the weight of street-cars and steam railroad cars. They have recognized the fact that vehicles should be as light as possible to reduce the wear and tear on the road-bed and to conserve the power required for operating them. Good engineering dictates the same improvements in the elevator car. The first all-aluminum and "micarta" cars were built and installed at East Pittsburgh in 1930. The metal parts of the car safety and sling, as well as the car body, are made of aluminum and the car panels of "micarta" with a "celotex" core. These are large cars which will accommodate 20 people. The total weight, including all of the equipment mounted on the car, is 4000 pounds. This is one-half the weight which would be expected if the cars were built in the usual manner, using steel for the metal parts and bronze for the car body. The saving of 4000 pounds in car weight also reduces the counterweight 4000 pounds, making a total of 8000 pounds less weight to be accelerated to 600 feet a minute every time the car is started. The net saving in energy is at least one-half horse-power per start.

The design of the cars is very attractive, as shown by Fig. 1 and 2. The car should look as if it were intended to be started and stopped quickly and not like a closet or bank vault. It is important that the design should denote the use and should indicate lightness and agility. The hatchway doors should follow the same design and should not look like church doors intended to be opened at infrequent intervals. On the installation referred to above, the door-frames are aluminum with "micarta" panels, and the weight is less than half that of the ordinary design.

The increase in car speed above 600 feet a minute has resulted in the design of better types of car safeties, which are applied more

quickly and make a smoother stop. The centrifugal-speed governor which formerly operated only when the car had reached an excessive speed can now be provided with an inertia feature which will trip the

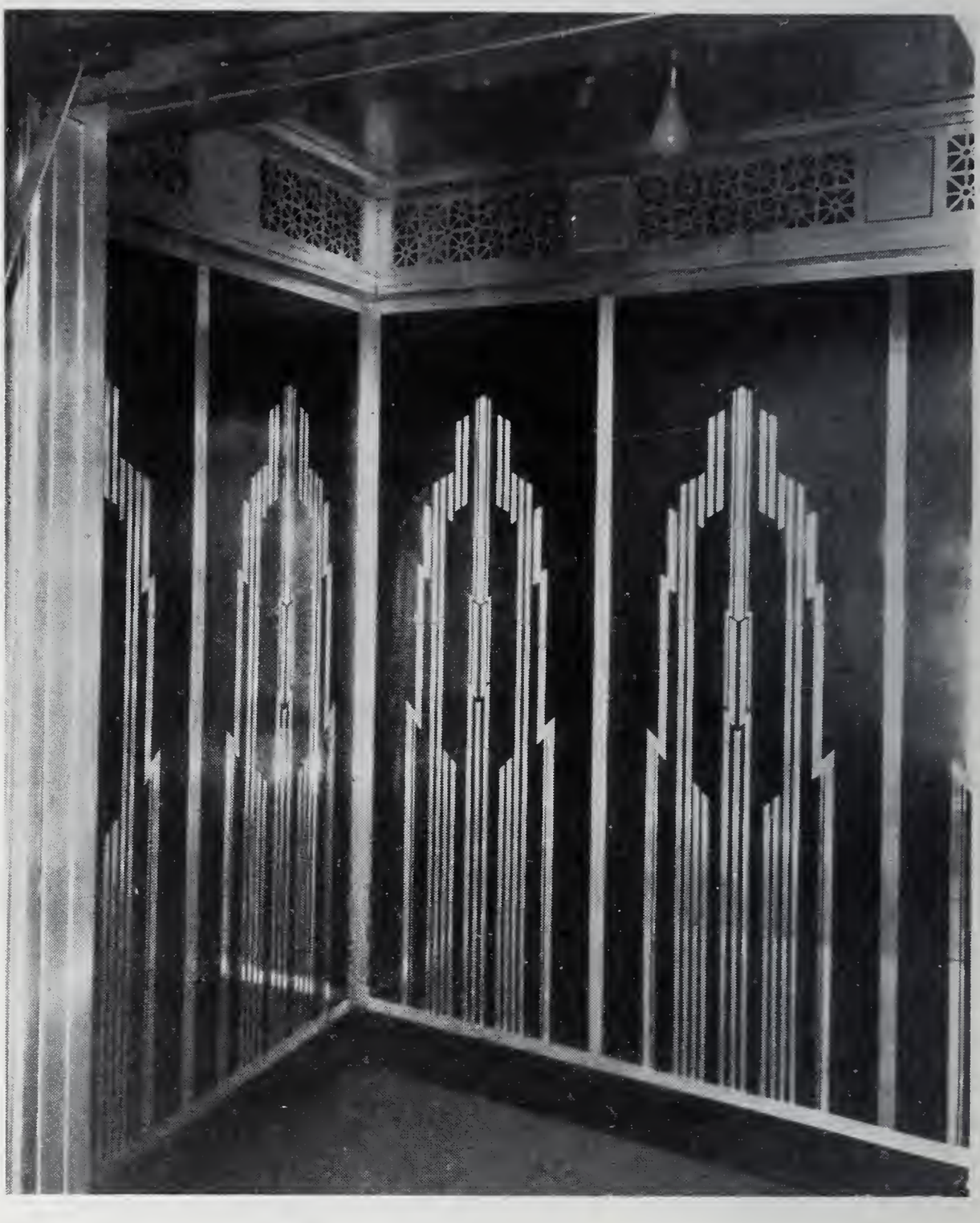

Fig. 1. Interior of Elevator Car.

safety if the rate of acceleration of the car becomes excessive due to an accidental condition. This will cause the car safeties to be set before the car has reached a high speed.

During the past 10 years the improvements in the electric elevator have been so rapid that the designers have been unable to consolidate these improvements to the fullest extent. The next step will probably be a simplification of elevator control apparatus. In

Fig. 2. Control Station in Elevator Car Showing Distinctive Features of Design.

some of the installations this apparatus is so complicated that it requires the constant attention of a number of experienced men.

This progress has not been received with open arms in every quarter. Entrenched interests have opposed changes which necessitate redesign of equipment. Established organizations are reluctant to try out new things, all of which is equally true in every line of endeavor where rapid progress is being made. It is one of the ele-

ments that has added to the zest of the game and has spurred engineers and commercial leaders to exert their best efforts in pushing forward the elevator art. It has caused keen and unrestricted competition which always results in progress.

The single elevator is reaching its limits of efficiency. It is, therefore, necessary for engineers to devise better ways to utilize the long shaftways extending upwards through the buildings. These shaftways occupy space which might otherwise be rented and their number must, therefore, be kept at a minimum. Several solutions have been offered and some of them put into operation.

The floor area and, therefore, the number of passengers carried can be doubled by using a two-story elevator cab. This requires two loading levels at the entrance to the building and each cab will ordinarily be stopped only at the odd or even floors. It was thought that the spacing between the cages imposed a definite limitation in the design of the building by requiring the floors to be spaced at equal intervals. This limitation can be overcome by arranging to change the spacing between the two cabs automatically in transit to adapt it to different floor spacings. At the entrances the cabs can be moved within eight feet of each other to reduce the height of the loading ramps. As the cars move to the first stop the space can be increased to 12 feet or more to accommodate the spacing at the upper floors. An installation with fixed spacing between cabs will be put into operation in New York in the near future.

The dual elevator is a more flexible solution of the problem. This consists of two separate elevator cars operated in the same shaftway. The first installation of this kind was put into operation at East Pittsburgh in 1930. The cars run on a single set of rails and both counterweights use the same rails. Each car is operated by a separate hoisting machine with its control system. The ropes for the lower car pass down either side of the top car. The arrangement is shown in Fig. 3 and 4. Three separate elevator cars can be operated in a single hatch in a similar manner. One or more of these cars could be double decked if advantageous.

The clearance required between the sides of the car and the hatchway will be a little greater than for a single elevator; for large cars this may increase the hatchway area by 10 per cent. The two hoisting machines can be mounted one above the other on a common

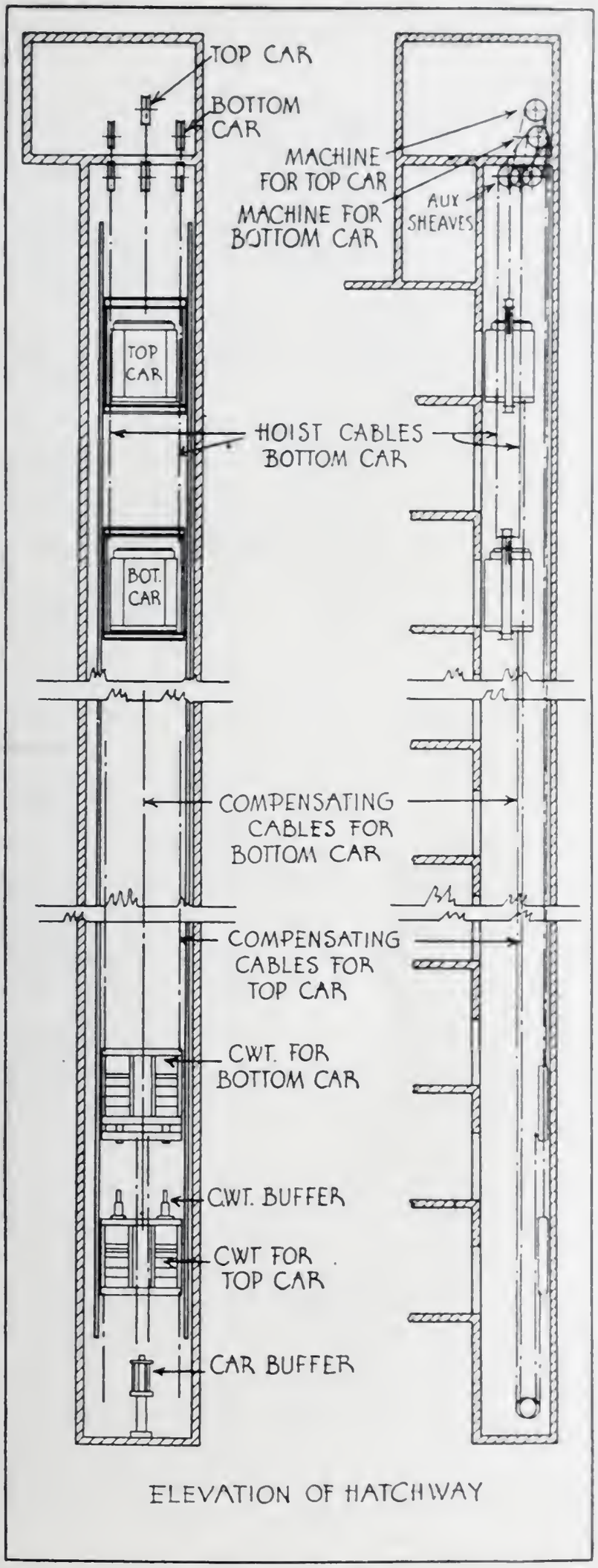

Fig. 3. Vertical Cross-Section of Hatchway Showing Arrangement of Dual Elevators.

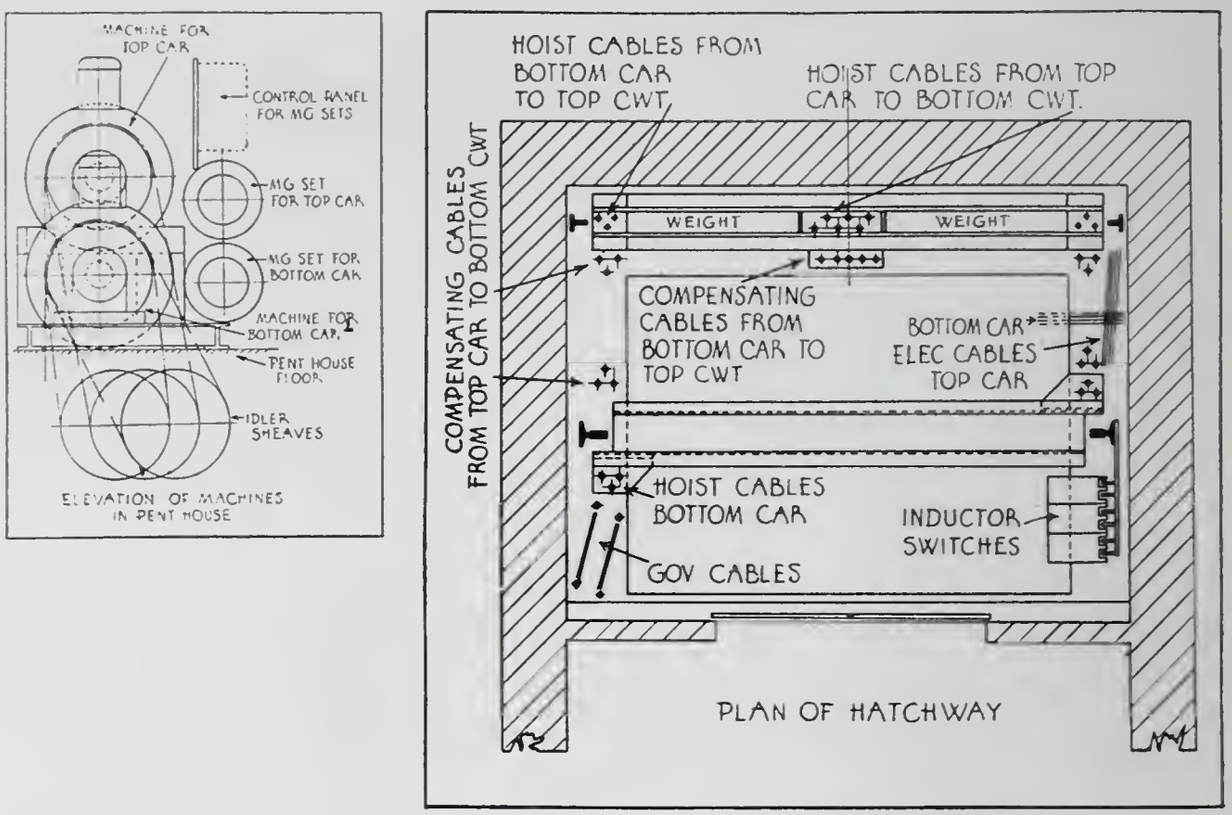

Fig. 4. Arrangement of Penthouse for Dual Elevators.

bed-plate so that the penthouses will not be any larger than for a single elevator.

The initial cost per elevator will not differ materially from that for single elevators, as the extra cost of the dual elevator equipment will be offset in part, at least, by savings in the hatchway construction. There will be a saving in the corridor space required for serving the reduced number of elevator shafts. This saving in corridor space will be at least equal to the space saved in elevator shaftways. Fewer hatchway doors will be required, as a single elevator may now be used for night service, stopping at the landing in both the local and the express zone. During inactive times of the day one elevator can be parked at one end of its travel and the other elevator used to serve all of the floors. A freight elevator may be installed in the same shaftway underneath the passenger elevator and operated on the dual system during the inactive times of the day, thus saving the expense of a service elevator shaftway.

Dual or triple operation will require automatic dispatching. The top car will leave first, traveling at a high speed through the local zone; about two seconds later, the local elevator is dispatched, making its customary stops, and both elevators should arrive at the

upper limits of travel about the same time. When both have reached this limit they can be automatically dispatched to the entrance level, the lower elevator arriving two or three seconds in advance of the upper elevator.

Another solution will be a continuous series of elevators moving up in one shaft and down in the adjacent shaftway. Designs of this kind have already been worked out and undoubtedly will be put into operation when conditions require them.

The escalator is an important adjunct to the elevator as a means of vertical transportation, as it is capable of moving a large mass of people through relatively short rises. It has been in commercial use since 1900, but has been improved very little in the past 20 years. It is probable that some important developments in this apparatus may take place in the near future owing to its widening field of application and more active competition.

The use of duplex and dual elevators will require ingenuity in the design and arrangement of the entrances of the building. This may lead to new departures in architectural design. Escalators may be used for conveying people between the various entrance levels, and ramps will also probably be used. The building will have double- or triple-decked entrances, and persons entering will be segregated at the level at which the elevator reaching the desired part of the building can be entered. This, in turn, automatically segregates the building into vertical zones so that it becomes in reality two or three buildings superimposed, one upon the other. This entrance arrangement will reduce the width of the corridor, as a smaller number of people will make use of each of the different levels, and in this way space will be conserved.

Vertical transportation is one of the most important problems in congested areas. In the lower part of New York it has been stated that the number of passengers carried vertically is three times the number carried horizontally in a working day. This has its effect on the design of the building. The larger the area of the building, the smaller the number of persons required to be moved vertically per unit of floor area. The Merchandising Mart in Chicago, the largest building in the world, is arranged so that the different classes of activity occupy single floors. In this way a purchaser coming to the building walks from one office to the other and may use the elevators

only a few times during the day. The concentration of a common business activity in a single building conserves the time of persons transacting this business and illustrates the real function of the large building. These buildings have not of themselves produced congestion; they are to a large extent relieving the street congestion by making it unnecessary for persons to go long distances from one building to another to transact their business. They are performing a real service in sections where the volume of business has reached large proportions, and are therefore the most efficient. It is not uncommon to have buildings occupying an entire block, and we now have projects which will comprise several blocks in area.

In order to economize the space required for elevators it has been proposed to create an upper distribution level, sometimes called a "plaza floor," where passengers change elevator cars when going above or below this level. On this floor are located barber shops, beauty parlors, restaurants, and merchandising centers. In a large building, such a floor may become a village in itself so that persons using the upper part of the building may prefer to transact their business on this floor rather than the street. This, in turn, reduces the load on the elevator system.

It is not much of a step for our imagination to picture a series of such buildings having their plaza floors connected by bridges and corridors which would become virtual streets extending through the area. A person desiring to go from an upper story of one building to a similar location across the street would not have to descend to the street level and fight his way through traffic to reach the elevators in the other building; he would use the upper level and save both time and energy. This would still further reduce the load on the elevator system. Express elevators could operate from the subway and ground floor to this upper level. Persons using the subway would walk to and from the station at the upper level and then take an express elevator directly to the track level.

The zoning laws have produced a new form of architecture. The introduction of new methods of vertical transportation with the possibilities of interconnected buildings may result in another distinctive type of architecture.

DISCUSSION

C. N. HAGGART, *Chairman:** I think Mr. James has tied his subject in very well with building construction. We want to hear from any one who has any question to ask, or who would like to discuss this paper.

L. J. RIEGLER:† With two or three elevators in one shaft, how are the lower elevators suspended to get by the upper elevators?

H. D. JAMES: The ropes to the bottom car straddle the top car; half of them go down on one side of the hatchway and half on the other, and that is why you can get three elevators in one shaft. The compensating cables for the top car straddle the bottom car. Come to East Pittsburgh and see it.

C. N. HAGGART, *Chairman:* Mr. James didn't mention his elevator for parking of automobiles. I am sure he will be glad to say a word or two about that.

H. D. JAMES: Mr. Chairman, I rather object to that being called an elevator. There are a good many limitations imposed on it when you use the term elevator to describe it. The device is an endless chain like an elongated Ferris wheel, with containers, one for each automobile. Some time, perhaps, I will tell the Society more in detail regarding it. The automobile is put on and taken off at the same level. The device is not used for transporting material between levels, as with an elevator.

There is a parking station at East Pittsburgh that has space for six machines, each having a capacity for 24 cars. It is 105 feet high, and the ground area is 16 by 24 feet for each 24 cars. The building is simply a steel structure, with tile walls surrounding it for weather protection. The load is carried on a structural track, and the building carries none of the load. Two of the six machines have been in operation for over a year.

C. N. HAGGART, *Chairman:* Are dual elevators now being installed?

*Consulting Structural Engineer, Pittsburgh.
†Assistant Engineer, Pennsylvania Railroad, Pittsburgh.

H. D. JAMES: We considered them for the Marshall Field building, which is the largest building now to go up in Chicago. You know that after the steel work for the building is designed, any one suggesting a change is not popular, to say the least. Considerable time elapses between the architect's plans and the construction of the building, therefore construction now undertaken was too far advanced to be readily adapted to dual elevators. Right now there is an opportunity for improvements to existing buildings to modernize them. There are many buildings in which dual elevators would not be the proper thing. Probably the first dual elevator will be put in a building that will not be economical without it.

As a people, we are conservative. Buildings cost several million dollars, and we don't want to take chances. There are a number of old buildings that will have to be renovated. We may find space in those buildings to put parking machines and thus improve the occupancy of the building.

A. V. KARPOV:* Are there any chances of putting dual elevators in old elevator shafts? Taking, for instance, the Oliver building, is it possible to increase the capacity of elevators in this building by substituting dual elevators instead of single ones, and what changes are necessary in the building to accomplish such a change?

H. D. JAMES: The Oliver building management is very much alive to the situation, but I don't believe that it will accommodate itself to such a proposition.

Before the contract was let for the Frick building, serious consideration was given to the use of dual elevators.

*Designing Engineer, Aluminum Co. of America, Pittsburgh.

ARCHITECTURAL PROBLEMS OF BUILDING CONSTRUCTION*

By Alfred Shaw†

Representing a large firm of architects, I feel happy to talk to engineers because of the closeness of our respective activities; it is only by reason of the preponderance of the esthetic or the scientific in any problem that there are two professions to-day. The older, my own, has come to be considered the more esthetic and yours, the engineer's profession, has come to be considered the more scientific; but an architect can not successfully exist to-day without being something of an engineer, or at least having an appreciation of the value of the best engineering advice. In the great and interesting problem of the building of this country our paths must cross and parallel each other a great deal.

The methods of approach and study for various architectural problems are so different that the details of one may be absolutely different from those of another, but one governing principle should control them both; that is, fitness to purpose, and relation to human happiness.

I might at this point choose a typical problem—a sky-scraper, and venture into some detail on what seems to me the architect's relation to it. I will try to speak of the very best way of handling the job, whether it has been our way or the way of some other architect.

An architect, to be a good one, profits by the experience of previous commissions. It is his job to guide his client in every way. He should be able to say whether the proposed site is a good one; and, when the problem is questionable, he should be able to analyze the whole matter.

It is a very definite part of an architect's preliminary work to consider all the psychological questions connected with the project. In the case of residences, the exposures and vistas become important; in the case of development of metropolitan real estate, the districts and their likelihood to change must also be carefully weighed.

Let us consider the office building. Given a location in a business district, we take the available site, make sketches until we find

*Presented November 5, 1931. Received for publication December 10, 1931
†Graham, Anderson, Probst & White, Architects, Chicago.

the most workable plan, and develop it to the limit legally allowed by building codes and zoning laws. Then, by the use of costs per cubic foot, estimating rental costs per square foot, and the method of financing, we come to some conclusion as to the economic aspect of the project. An architect should not only be able to arrive at an intelligent answer to this question, but, should he arrive at an unsound or negative answer, he should have the courage to advise against the construction, event at the cost of his losing the commission. This may seem a little outside the architect's technical work, but some of the information essential to a decision is available to the architect only.

After discussing this aspect with the owners, he then proceeds, to the utmost extent of his ability, to develop his best ideas. The floor heights should, for instance, allow 10-foot beams in a typical space; the best outside space should not be deeper than 25 to 28 feet, and should open on courts or streets that are wide enough for good light and air. The column spacing must be studied to give a workmanlike framing plan and, even at the beginning of a job, before the engineers have gone into the structural details, the planner of a building must include the knowledge of what a good structural plan is. Column spacing must be governed by what makes for the best division of offices; in other words, a structural bay of 17 feet will break up into two units, each with a window, and will give offices slightly under nine feet in width. Any great reduction from this 17 feet would result in a bay too small to subdivide. The planner must know that elevators will be about one to every 25,000 square feet, and have a departure interval of between 15 and 20 seconds. Knowing in advance the general sizes of floors, structural walls, and columns, he must anticipate the location and sizes of steam and water risers, wire shafts, elevator shafts, and ventilating shafts, and each element must dovetail into the other so that when put together the interiors are well planned, well lighted, and fine looking. All this should be within an exterior—whether in masonry, metal, or a combination of both—which contributes to an inspiring ensemble.

We know, for instance, that the lower stories where the pedestrians swarm should be hard, clear, and not porous; granite and pure unplated metals are ideal for this. Above this, stone, brick, and terra-cotta, with an increasing use of metal and glass, work out very well.

On the Koppers building here in Pittsburgh, we succeeded in having adopted, for the first time in a large structure, at least, the aluminum spandrels which are now so widely used. Aluminum, and stainless-steel alloys are gaining in popularity and I believe materials of this nature with great tensile strength, requiring little or no upkeep, will continue to become more popular with study of their uses and resultant reduction in cost.

You have perhaps noticed in our recent buildings that there is a constant tendency towards elimination of detail. This applies, not only to simplicity of ornament, but sometimes to the absolute elimination of decoration. Some of our buildings are so simple as to be startling. Although I would not dare venture a prediction as to the probable trend of American architecture, we have one principle by which we may be guided—the principle that the vogue is always changing. Styles move in certain directions, and when they go as far as they can there is nothing else to do but turn around and go in another direction. This is true in ladies' dresses and in decorative styles, as well as in architecture, and I feel that the absolute simplicity in some of our latest buildings may after a while become more or less tiresome.

Having arrived at a general plan which meets the criticisms of ourselves, our clients, and any one else who may have been asked to confer on the matter, a set of very complete sketches of all floors (including interior and exterior designs, illustrated by perspectives) is assembled and approved with the changes which become obvious and advisable at this time. The next move is the development of working-drawings on a larger scale, with the knowledge that rule-of-thumb dimensions for mechanical equipment, ducts, structural sizes, depths of beams, wire shafts, and general electrical requirements must be discarded and more accurate plans and requirements laid out by the various mechanical, structural, and electrical engineers. These naturally conflict, and the labor of dovetailing begins. In the development of this dovetailing, one or sometimes two main squad bosses must become familiar with every feature of the job and reconcile the various sets of drawings to make sure that two or more items do not occupy the same area.

An office building is a commercial proposition, built for income; and, as the materials are selected and their forms and locations are

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developed, the materials must be considered very carefully in relation to their upkeep, not only for daily maintenance, but for length of life and for contours adapted to cleaning.

To give you some idea of the various specialties which have to be considered in every detail, I am going to bore you with a list and try to recite it slowly enough to impress you with the burden of each item—acoustics, boilers, carpentry and cabinet work, tile, coal-handling equipment, directional signs, ejectors, burglar protection, electric wiring, elevators, steel erection, fire-protection system, foundations and masonry, glazing, granite or stone and marble, hardware, heating, structural tile, hollow metal, incinerators, lighting fixtures, mail chutes, ornamental iron and bronze, painting, plastering, plumbing and gas fixtures, roofing and sheet metal, stack insulation, terra-cotta, terrazzo, vacuum-cleaning system, safety-deposit vault, window shades, and wrecking. All of these subjects are considered in the making of the drawings, treated in accurate detail, and so set up in the specifications that when the next stage (that of estimating and building) comes, the client is equipped with a prescription or instruction to build this building which will stand up legally, and not only be clear to contractors, but also be so worded that there is no question as to the legal status of any matter. There are usually four sets of drawings—architectural, structural, mechanical, and electrical. The post-office in Chicago required 280 drawings.

We present all of the full-size details for these estimating sets because it not only gives the contractor more accurate information, but results in lower bidding, and there is no element of chance as to how the detail might work out, assuming that the bidding is competitive—and I might say that to-day most building is competitive. (Some of our contracting friends who were inclined to be "choosy" in the good old days are very happy to bid on almost anything now.) When the estimates come in, a careful tabulation of each is necessary, and in considering this tabulation a knowledge gained only from experience and observation of the personal quality and professional reputation of these bidders is also necessary. As I stated before, the contract must stand up legally, but no one wants to be harassed by an agreeing party who is constantly under suspicion. As one of our partners so accurately put it, "If we need a bond we need another contractor."

All these details having been completed for the job, there is still nothing built and, although most of the work is then up to our collaborators, the contractors, a very important part of the architect's work is beginning. I would like to say here that the ingenuity which has been put into building American cities has never been exploited in a dramatic or literary way. Architects and engineers have been praised to the skies, sometimes damned, but in the great clamor I would like some time to hear a properly voiced admiration for not only the gigantic task of assembling these great mountains of material, but for doing it quickly, efficiently, and economically enough to allow the profit which is the just due of these great builders. The courage and skill of a great building contractor are things I would like to see recognized a little more adequately.

The superintendence of a sky-scraper involves a little organization of its own. There are always changes, some of which are anticipated early enough to have drawings made, while there are others which have to be done on the job. The checking of the costs of these changes and their co-ordination with all the trades which they affect requires a searching accuracy and constant attention. As the structural work and field work go ahead, constant supervision is necessary. The routing of all the electrical and mechanical equipment, ducts, pipes, wiring, etc., which can never be shown completely on a drawing, must actually be devised on the job, and can be done well or poorly, depending on the ingenuity and resourcefulness of the contractor and the architect's superintendent. As the building goes ahead, shop drawings are made to cover the fabrication of all the materials down to less than a hundredth of an inch, and checked against each other and against the original set of drawings.

Samples of materials are tested for their structural quality and chosen and approved as to color. Their texture must also be carefully considered. Development of ornament—three-dimensional study in clay of ornamental forms, which will give the building an architectural character—must also be taken up at this time. The appearance of all of these ornaments and materials is as much a matter of experience as actual observation. Holding a piece of brick or marble in one's hand will usually give no accurate idea of how that same item will look built into a wall when seen from a distance.

There is also the unpleasant subject which must always be recognized; that is, overcharging, either accidental or intentional, by some hard-pressed contractor or subcontractor. Although I have an honest and sincere admiration for contractors in general, it is no secret that an architect's duty to his client involves the most hawk-like attention to this particular matter.

As the job is completed, there may be changes that only actual construction would make obvious. Finishes and colors of paint are determined and finally the project is turned over to the owners—sometimes with a great flourish including a celebration, and sometimes merely by quiet procedure and simple occupancy. Soon the faults as well as the virtues of a building become obvious to everyone, and especially should they become obvious to the architect himself, because it is only by seeing mistakes and admitting them that we are able to improve our craftsmanship. The observance of a million errors made by other people makes no such impression as becoming aware of an error made in one's own experience. I think, however, that the architectural profession in America can be really proud of its achievement.

Just within the last month we have wrecked in Chicago, to the tune of much publicity and observation by large committees, what is without a doubt the first metal skeleton-frame office building erected, in a sense the parent of the sky-scraper. From this humble beginning developed the outstanding achievement of American architecture—the modern sky-scraper. From the forms, the details, and the character of the sky-scraper, the architecture has gone into all kinds of decorative channels, and many of the things which were developed in the sky-scraper have been used by Europeans for buildings which are not nearly as high as the buildings which we have in this country. There has been an unfailing spring of enthusiasm and ingenuity to develop this new architecture of ours and it has produced the great dramatic character of our modern American city. I think that we can all feel confident that the continuation of this ingenuity and enthusiasm, maintained through years to come and controlled by a desire for order as well as by the most accurate prediction of the future which our vision can give us, will make the already great achievements of our American cities seem what they really are, the first

consciousness of the great possibilities of monumental comprehensive city planning.

DISCUSSION

C. N. HAGGART, *Chairman:** Mr. Shaw has given us a splendid description of some of the problems involved in architectural design and construction and incidentally has given us a very good idea of what the relation of the engineer to the architect may be. I believe that is very important, because we can't function properly unless we understand the problems of our associates.

L. J. RIEGLER:† I would like to ask Mr. Shaw to go further into his subject and tell us something about working out the economics of the building, indicating whether or not he uses real-estate experts, for instance, in determining the probable business the structure will have; also I should like to have him say something as to places where air rights over railroads can be utilized economically. There has been some talk of constructing buildings in congested districts without windows for the lower floors, say for four or five floors from the street. I should like to know whether or not his firm has been doing anything along that line.

ALFRED SHAW: With most of the buildings we have built, the places where they have been located have had an apparent value or else the project has not gone ahead. Mr. Graham, my senior partner, has a knowledge of building and a knowledge of real estate that is much superior to that of most real-estate men. Frequently an owner is a real-estate operator or an owner may have a real-estate expert to take care of certain things, and, in that case, of course, the criticisms are very good to have. Generally speaking, it hasn't been our practice to do that, chiefly due to Mr. Graham's excellent judgment about those matters.

I can't say much about the second subject—air conditioning, I suppose you might call it. The most extreme example I have heard of is the building of the Simmons Saw Company. I have seen pictures of it; a published perspective shows no windows at all. The air is conditioned, and the building is artificially lighted. A completely

*Consulting Structural Engineer, Pittsburgh.
†Assistant Engineer, Pennsylvania Railroad, Pittsburgh.

artificial condition is created inside a closed box. It was built on the theory that they can get three shifts working in one day; the conditions are always the same and are always excellent, theoretically, at least.

One of the most interesting buildings I have seen built is that of the A. O. Smith Company in Milwaukee. The whole building has artificial air conditioning.

Theaters are windowless, as we all know, and in recent years we have air conditioning in most new theaters. We are installing ducts for heating or cooling, as may be required, in the first four floors of the new Field building in Chicago. As far as I know, this is the first general installation in an office building.

E. B. Lee:* I have enjoyed Mr. Shaw's paper very much, and being a worker in the architectural trade I think you have been very fortunate to-day in the selection of the architect to read such a paper before you.

From the material and handling of Mr. Shaw's paper, I suspect that he belongs to that class of architects known as designers. You know that the architectural business, in the production of the sketches and working-drawings from which big buildings are built, is a very complicated business. It requires the closely organized co-operation of a great many men with special qualifications. This is particularly true where "heavy" work or large building work is being done. Even those who work at it and are familiar with its complications are amazed at the endless ins and outs that go with the composition of an architect's ideas and the putting of them on paper in terms that contractors and workmen can understand, thus permitting the erection of great buildings that express the commercial epoch in which our country is now so actively engaged. Many men of many minds are required to work out the different designs and make the drawings for the different trades whose work is incorporated in these buildings. In the architect's trade, there is a saying that if you really want to know what is in the building you might just as well ignore the architectural big boss and go and ask the designer. He is the man who knows the intentions and the fine points, who has put it together in the first place, and has followed it through.

*Architect, Pittsburgh.

Among the architects themselves, they reserve their appreciation and credit for successful building work for the designer. The architects here, I am sure, enjoy very much the old question of which is the older profession, the architect or the engineer. This is a sure-fire point that must never be missed in the meeting where the architects and engineers are present. The architects like to claim that the architectural profession is the older. The tonsorial calling is older than the medical profession, and there is evidence that the barber, who practiced bleeding, was the first medical practitioner. This question has the same importance as whether the architectural or engineering profession is the older.

On heavy work like that Mr. Shaw discussed, the architect can not get along without the engineering profession in almost all of its branches. The engineer, as a specialist, contributes the design of the foundation on which the building stands, its structural frame, and its pipe service bringing water, power, and light to all the uses that they are put to in a building. The engineer carries, in the architectural business, a heavy load and makes a magnificent contribution to the architecture of America. Of the work that he does, little is on view when the building is finished. The art or architectural side of the building receives the principal consideration because it is that part of the work that is seen. We like the engineers around our offices and we have had to have a lot of them to do our work. The only kick that I have about the engineers is that I have paid them a lot of money and no engineer ever paid me anything that I can recall.

The architect, whether he earns it or not in building work, takes the lead. He does this because his methods of designing are those that are exercised first. The architect is the fellow that is asked first. He makes the first sketches and has the opportunity to originate the first ideas out of which big building work takes shape.

No big buildings like those designed by Graham, Anderson, Probst & White are the work of one man. These buildings, when completed, are the works of many men, selected, classified, and given opportunity according to the work that is to be done. In all big buildings there are opportunities, and there is honor enough for everybody.

In Mr. Shaw's paper, you may perhaps have received the impression, as I did, of the enormous number of items and details that

have to be considered, controlled, and co-ordinated in the great organization that makes the plans for work of this kind. The results that have come from that organization, in the case of Graham, Anderson, Probst & White, are among the best results that have been obtained in big building work produced by any architect in America, and yet greater things will be done in the future.

At one time a great Chicago architect, with whom some of Graham, Anderson, Probst & White's organization were trained, said, although these may not be his exact words, "The things that our children and grandchildren will do, if we could see them now, would astonish us." The future of materials, methods, and results in the building of fine structures is beyond our imagination.

When we were young, our main worry used to be the fact that all the big jobs in our town were given to some strong architectural organization in another city. This is the perennial question of patronizing the outside architect. We used to worry about it while we were on our way to the jobs that we were doing in other towns outside of Pittsburgh. We know now that when we are able to do better building work in any class of buildings than Graham, Anderson, Probst & White we will get the job in Pittsburgh.

George W. Thomas:* Mr. Haggart has asked me to say a few words about lighting. For the last five or six years I have made the study of natural lighting of buildings more or less of a hobby. Natural lighting has been taken more or less for granted by engineers and men in the street. It really is both quantitative and qualitative. It can be analyzed just as thoroughly as the structural parts of the building. It reflects on the economics of the building, its rental value, and its neighborly character.

In New York, Chicago, and in some instances here, we see the "set-back" building. There are reasons for this. One of them is that the "set-back" construction provides a wider "sky angle" for those windows that look upon narrow streets from the lower floors of buildings across the street. Whether or not the higher buildings are stepped back in their proper relation to the needs of the neighbors is uncertain, but I am sure that a proper study of "set-back" regulations in relation to good natural lighting will establish new regu-

*Chief Engineer, H. H. Robertson Co., Pittsburgh.

lations that will lead to greater freedom of design and more graceful proportions than are exhibited in some of our older high buildings.

This is but one phase of designing for daylight. Another phase is that of determining before a building is built whether or not the chosen daylight facilities are adequate to provide the required amount of light.

We all know that we should have plenty of light by which to see our work; just how much, the experts do not agree, but for ordinary office work, drafting, or similar work, they have come to the conclusion that 20 foot-candles of light per square foot is the minimum.

We have made a great many calculations from plans, to determine what the lighting of a building would be with a given outlook from the windows and a given sky condition. We have checked these calculations with instruments. We find a very close agreement—as close as can be expected with the variables that occur due to the changing aspects of the sky. It is possible, therefore, to design for daylight, and we feel that it is deserving of special consideration as a part of any building design.

Why should we consider lighting as such an important feature? In this room there are men from twenty to fifty or sixty years of age; half of you wear glasses. What does this mean? It means that at some stage in life your eyesight has been abused. Your parents, teachers or employers have permitted poor lighting conditions, and the result has been a large and widely distributed amount of what we may call crippled vision.

Some have a worse degree of crippled vision than others, yet more than half have some degree of crippled vision. When we stop to think that eyesight is responsible for 70 per cent. of the mental and muscular energy which we exert during our waking hours, even five per cent. of deficiency in vision is important, but five per cent. does not cover it. The deficiency in vision ranges anywhere up to 70 or 80 per cent. That is an economic problem. It is a disgrace that we as architects and engineers have neglected so long this important part of our existence. We have five senses, but when we have 70 per cent. of our activities dependent upon the sense of sight, we can not afford to abuse it as we have been doing in the past.

The engineers have had a very good record in finding the source of trouble in such things as malaria, typhoid and yellow fever. Engineers can find the cause of all this crippled vision and they can also find the remedy. To show what we have been able to accomplish and to give you a little better idea of how the problems can be tackled, I wish to present a few illustrations.

Fig. 1 shows remarkably close agreement between calculated predictions and actual measurements. The lower dotted curve shows computed results; the full and somewhat undulating curve shows the

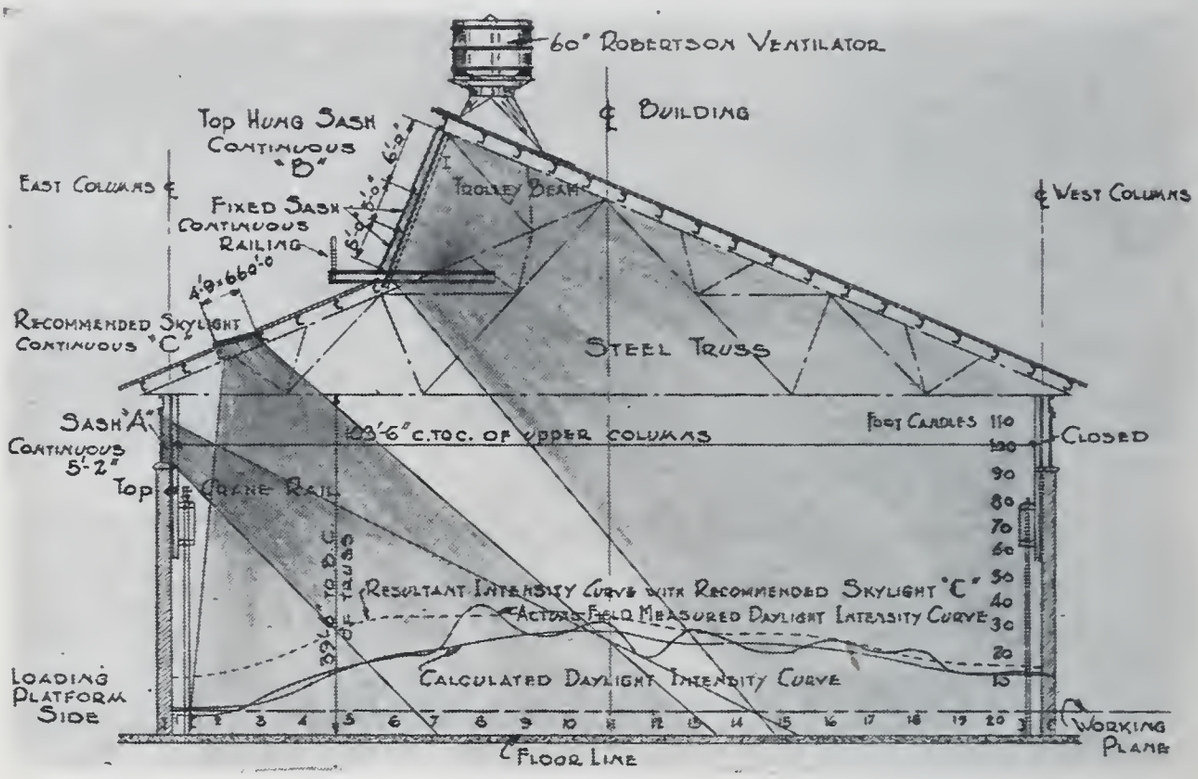

Fig. 1. Cross-Section of Building Looking South.

actual measured results; and the upper dash curve shows the improvement that might be expected near the left wall due to the addition of a small skylight near the eave and below the saw-tooth sash.

Readings were taken at 11:30 A. M. on a fairly bright day, with some clouds. The undulations are due to fluctuation of skylight value caused by clouds and smoke at the moment readings were taken.

Fig. 2 and 3 show how equal amounts of glass may be made to produce different results even though similarly placed. In Fig. 2 the light intensity is extreme near the window, and falls off rapidly between the first and second stations. In Fig. 3 the intensity is not as

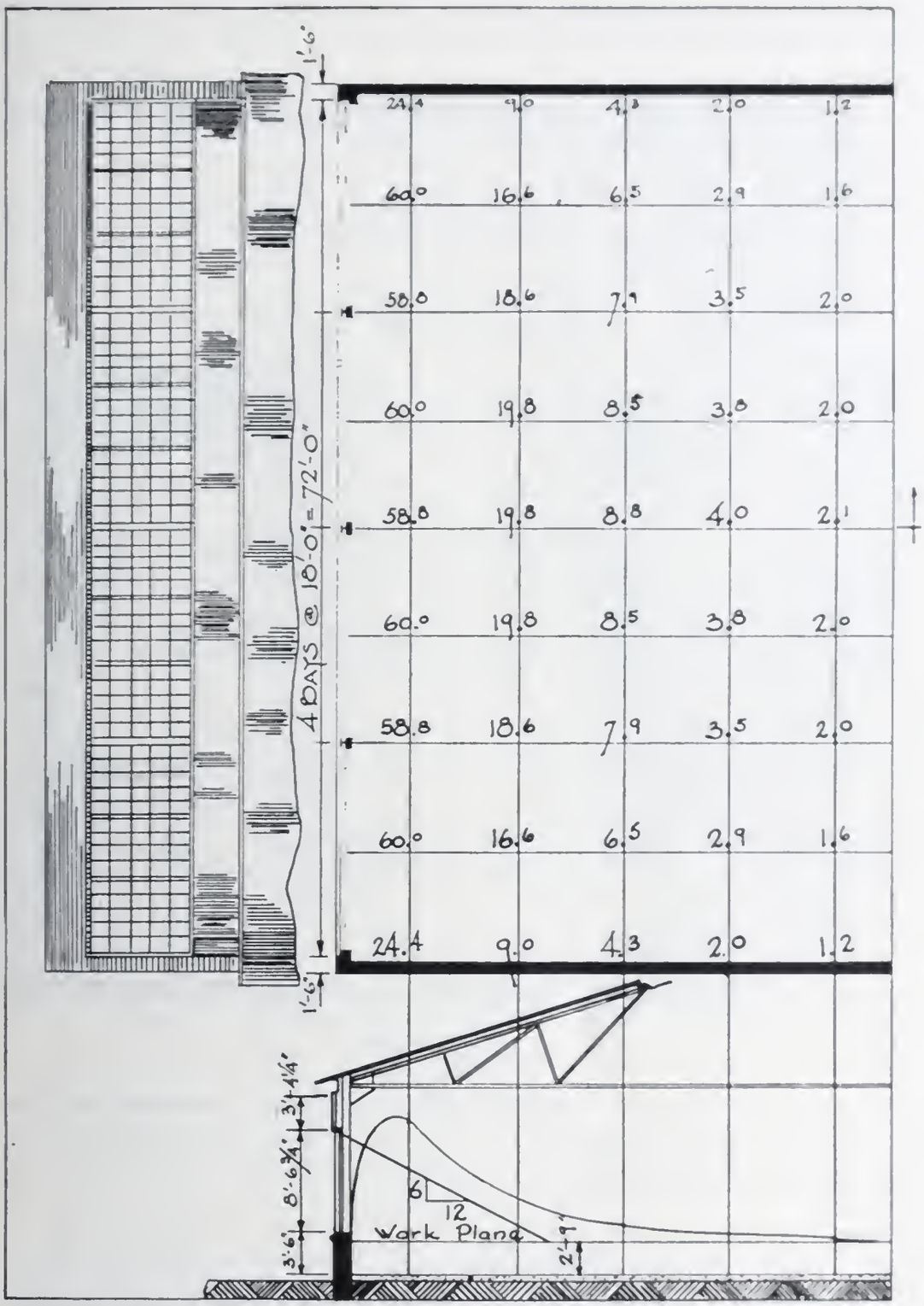

Fig. 2. Daylight Intensities with Continuous Sash.

great near the window, and falls off gradually between the first and third stations. The intensity at the third, fourth, and fifth stations is 10 to 25 per cent. greater in the case of Fig. 3 than in Fig. 2.

A worker in the room represented by Fig. 2, if required to face the windows, is subjected to continuous glare, while the same worker, in the same position in Fig. 3, has blank wall space for his visual background a part of the time, so the glare condition is minimized.

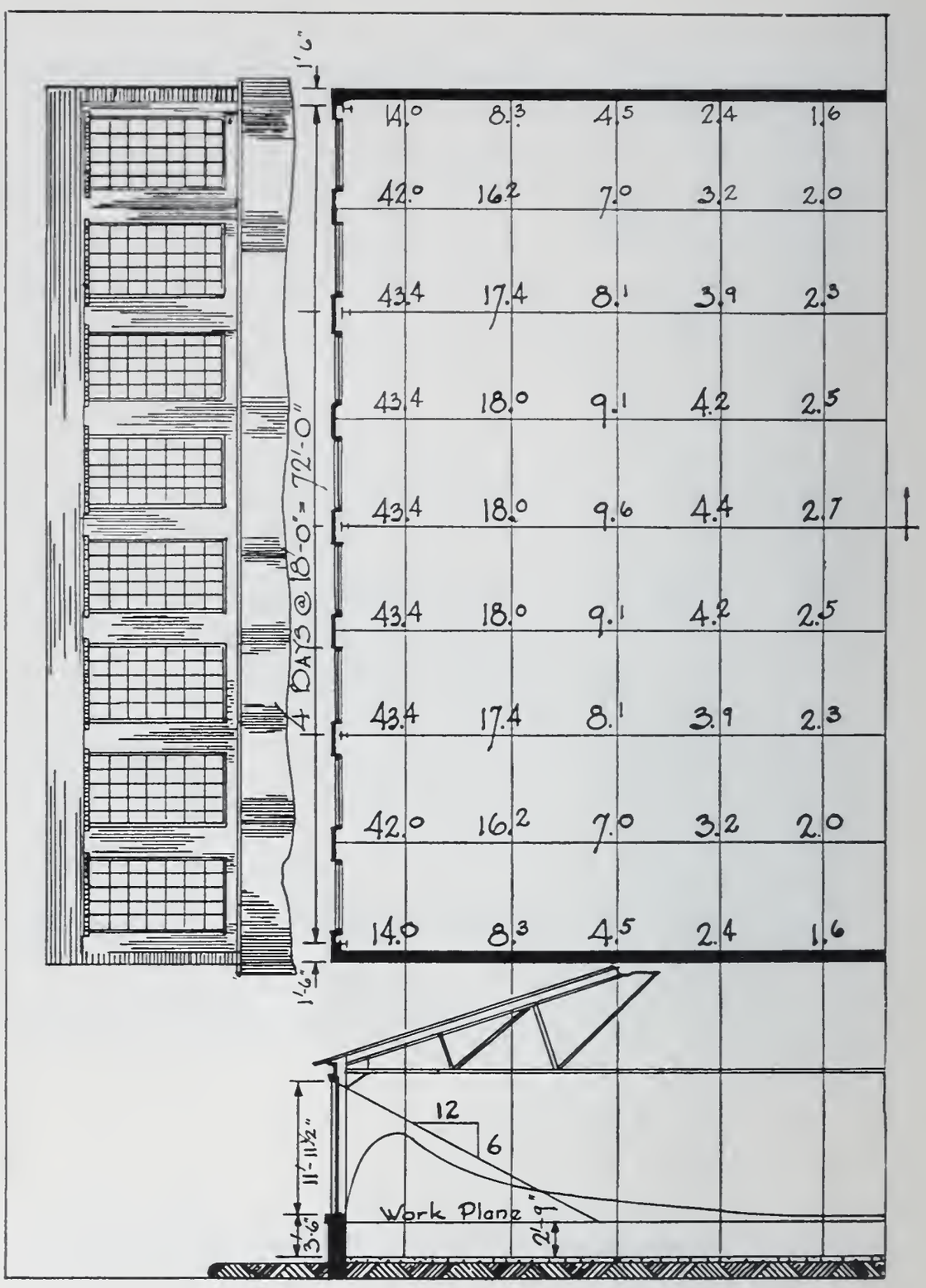

Fig. 3. Same Building Shown in Fig. 2 Using Same Amount of Glass.

Note that the point, where the 6 to 12 slope line from the top of the window intersects the work plane, in each case is at about the limit of adequate intensity.

Fig. 4 shows how glare may be minimized, and light intensity increased at the rear of the room. In general principle, there has been

nothing new in window decoration since the inside wooden blind was abandoned.

On the left in Fig. 4 is a typical modern window decoration. It is "upside down." The best light comes through the upper part of the window. The modern decoration uses the heavier drapery at the top of the window. The "glare zone," as one sits facing a window, is

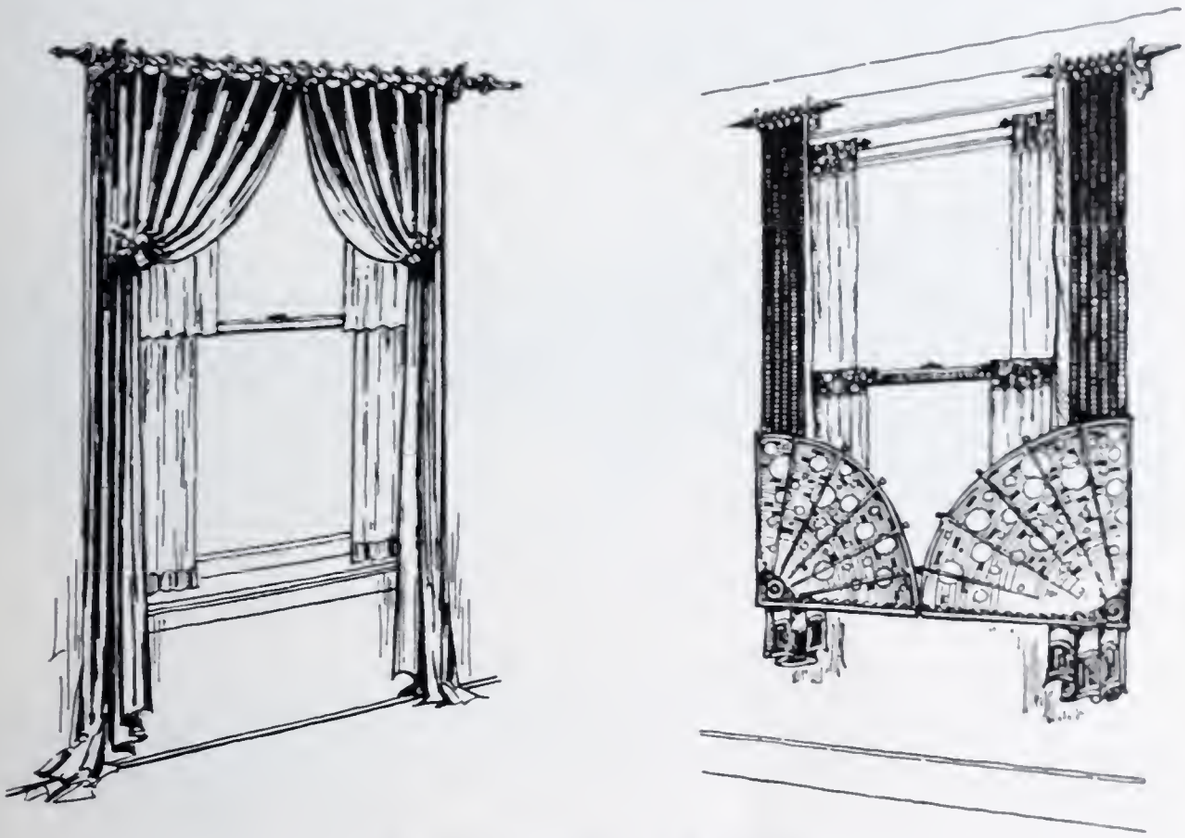

Fig. 4. Shading of Windows.

the lower half, which is left exposed. The upper part of the window is more useful in illuminating the rear of the room, yet modern heavy draperies interfere with this.

On the right is one suggestion of many thousand possible methods of improving window decorations. The decorations are "right side up" from a scientific viewpoint. The upper part of the window is open to receive the best light, and to direct it to the far side of the room where most needed. The heavier decorations are at the bottom of the window, not only eliminating glare but also giving privacy. The dust-catching "frills" are low and may easily be dusted or cleaned. Invert the page and note the similarity of the two designs.

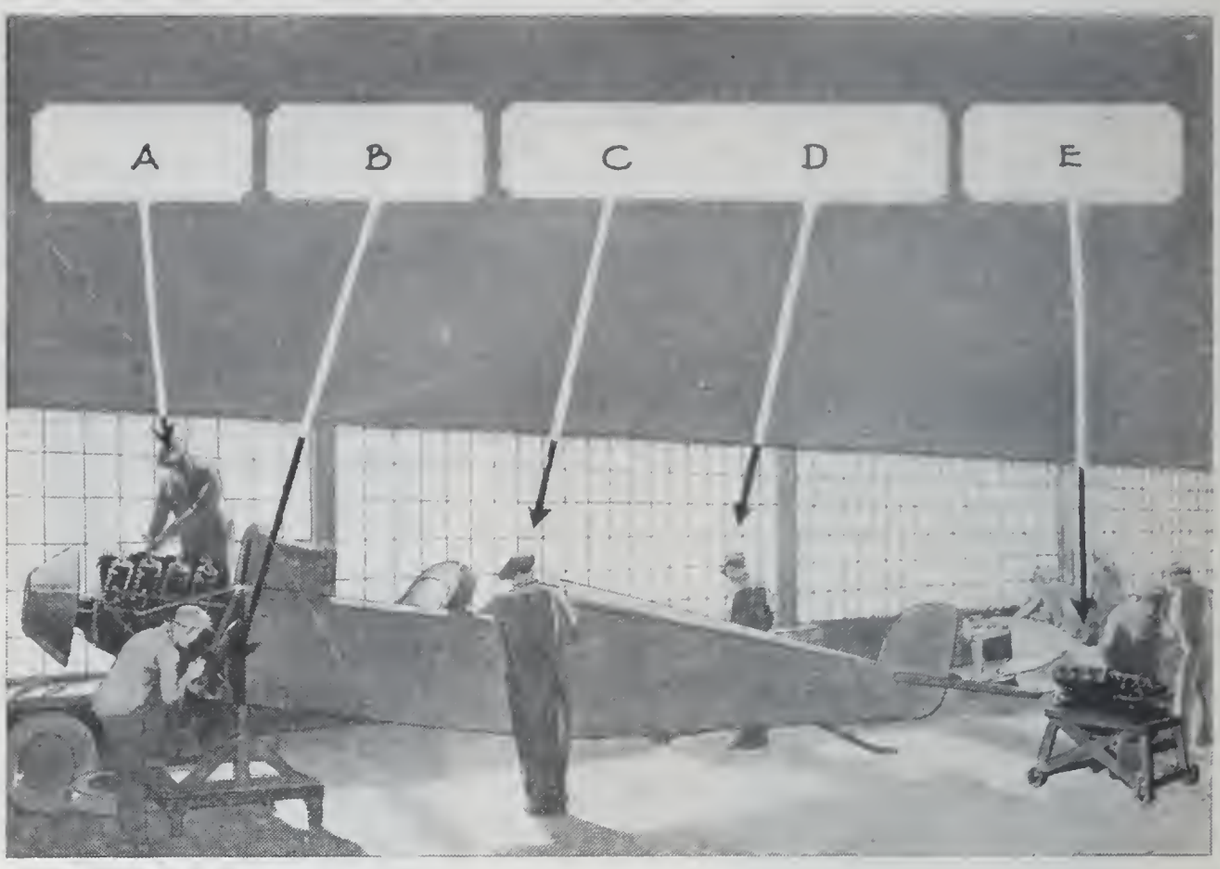

Fig. 5. Daylight Entirely from Windows.

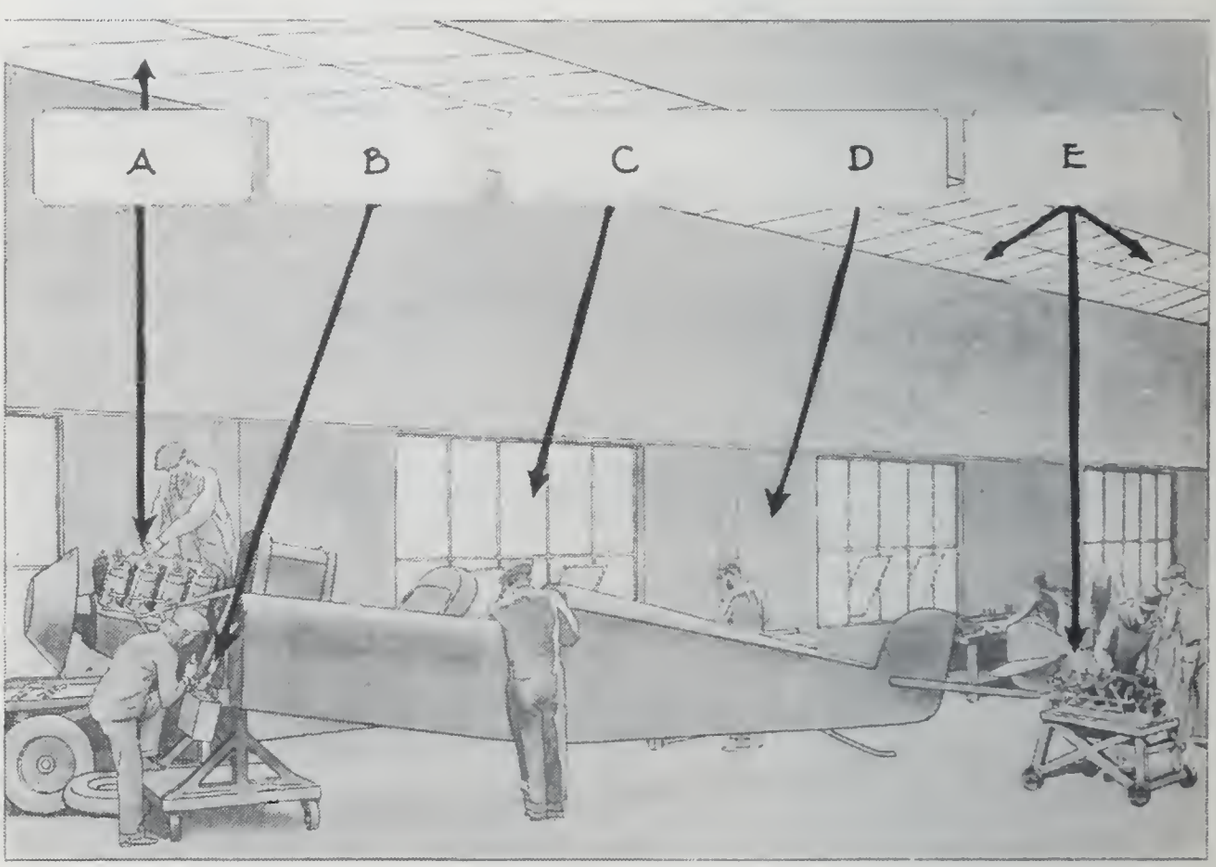

Fig. 6. Daylight from Combination of Windows and Skylights.

Fig. 5 and 6 afford a comparison of lighting methods. The principles of natural lighting involved in these pictures are not peculiar to the aviation shops. The removal of a large amount of glare from the field of vision and the addition of generous quantities of overhead light will do much toward the reduction of crippled vision.

The following features are evident in Fig. 5:

A. The workman is standing in his own light.
B. This man is working in shadows cast by objects between him and the window.
C. The glare from *continuous* runs of side-wall sash causes discomfort and inefficiency in men who must work facing the window.
D. A sudden eye adjustment is necessary every time a workman raises his eyes from the bench.
E. Working area is not effectively lighted through side windows alone.

In Fig. 6 conditions are improved:

A. Overhead lighting through skylights casts no shadows.
B. Overhead lighting eliminates dim and dark places in the working area.
C. Areas of wall alternating with windows provide resting places for eyes of workmen, and help to reduce glare.
D. The workman naturally takes a position at one side of the window.
E. Overhead lighting gives uniform distribution of daylight.

Mr. Shaw and the other speakers have emphasized the thought that the prevailing tendency of the times is for the occupants of any building to require more each day in the way of convenience and efficiency.

Good natural lighting in a building is not only a convenience but it promotes efficiency. It is an absolute essential to the health and safety of indoor workers. With the knowledge and implements now available, it is inexcusable that some of the past and present atrocities of poor daylighting be continued into future generations, thus perpetuating the day-by-day abuse of eyesight.

Adequate and satisfactory daylighting can be obtained in any building only by thoughtful engineering design. Fortunately, the methods of analysis are simple, as the preceding illustrations have shown. The benefits of daylight cost no more than indifferent or harmful results. Why, then, should not the architect or engineer feel it is his duty to design for daylighting?

STRUCTURAL DESIGN*

By Frank E. Brown†

INTRODUCTION

Structural design is an alarming subject for a short paper. Under this title there are almost unlimited possibilities. One might discuss the elastic theory and its applications; the properties of materials; the theory of reinforced concrete design; or the service loads of structures. I do not intend to discuss any of these and, therefore, will confine my paper to the service of the consulting structural engineer in the design of many-storied buildings.

It seems, sometimes, that codes and handbooks, and the published descriptions of hundreds of buildings might make it possible for men of slight experience and technical training and no natural aptitude to take the place of the consulting engineer with years of experience. We engineers know that this is not so, but I think it will be useful to look over a rather ordinary problem and renew our faith by noting how many questions come up in which the special qualities of the consultant secure either safety or economy, or both.

In treating this subject, I assume any commercial building of any considerable number of stories in height. It may be an office building, a loft building, a hotel, or an apartment house. I assume, as is generally the case in the preparation of the plans for such buildings, that an architect, a structural engineer, a mechanical engineer, and an electrical engineer are collaborating in the preparation of the design and drawings for the complete building. These may all be a part of one organization, or they may be practising independently, each with his own organization. In either case, each is responsible for his particular part in the design, not only to see that his design is correct and his drawing a proper illustration of the design, but to see that his design and drawings conform to the designs and drawings prepared by the others. I assume, further, the more usual case in which the architect handles the business part in the project, in obtaining the owner's approval, taking bids, letting of contracts, etc.

In order to discuss this problem I have divided the service that must be rendered by the structural engineer during the progress of

*Presented November 5, 1931. Received for publication December 5, 1931.
†Smith & Brown Engineers, Inc., Chicago.

any building, from the preliminary work to the completion of the building construction, into five stages with subdivisions as follows:

- Preliminary problems.
- Definite determination of construction.
  - Type of structural frame—structural steel or reinforced concrete.
  - Type of floor construction.
  - Type of foundation.
- Design and design drawings.
  - Typical floor.
  - Column loads.
  - Approximate sizes of columns, girders, and trusses, and approximate requirements for wind bracing.
  - Other floors and roof.
  - Foundations.
  - Column sections and column schedule.
  - Trusses and girders.
  - Design and details for wind bracing.
  - Completion of drawings for bids.
  - Final checking of the design and the design drawings, and cross checking of structural drawings with architectural drawings, and with drawings for the mechanical trades.
- Shop drawings.
- Supervision of construction.

I believe this to be a fair schedule of the progress of the usual many-storied building project. I will now take these several stages and mention some of the many questions that must be answered by the engineer as a part of his service, and also mention some of the details of his work in the development of the design.

PRELIMINARY PROBLEMS

The service of the engineer during the preliminary stage, while not more important than in other stages, is likely to appear so to owner and architect. It is here, perhaps, that his value is most apparent, where experience and judgment enable him to give approximately correct information to his associates in regard to the requirements for construction.

The architect is preparing his preliminary sketches, and information is required quickly so that he may know whether this or that lay-out is feasible or practicable and without excessive costs. Here the type of structural frame to be used will be discussed. Which is best or most economical, structural steel or reinforced concrete? What is the difference in cost? If the building is of reasonable height and lay-out for a reinforced concrete frame, what spacing of columns suitable to the use of the building will give maximum economy in the frame? Whether of reinforced concrete or structural steel frame, is the spacing of columns proposed by the architect the best for structural economy? If not, can the spacing be changed to produce a saving without materially affecting the architectural plan? What type of floor construction will be used to suit the lay-out desired or selected? Possibly the type of construction can be picked for economical structural costs without loss in architectural requirements or loss in efficiency of building lay-out. If there are several possibilities in type of floor, then approximately what are the relative costs?

What thickness is required for floor construction? It may be that a maximum number of stories is desired in a certain maximum height limit and an answer is required as to whether a floor that is not too expensive can be designed of sufficiently shallow depth to leave satisfactory ceiling heights in the desired height of story.

Questions in reference to the proposed architectural details of exterior walls will be discussed. The engineer must be able to say whether the proposed wall detail is practical from the viewpoint of support on the structural frame and, if not, what alterations should be made in the scheme. He must be familiar with building-code requirements in reference to such details.

Often the building is to have special features, such as large rooms without columns, or towers with offset columns. Approximate depths for the girders and trusses that may be required in order to provide for such features will be desired by the architect so that allowance can be made for all these in his sketches.

The type of foundation to be used is generally settled during this preliminary stage. This requires a knowledge on the part of the engineer in regard to soil conditions at the site or near the site. He may require more definite information as to soil conditions and should at this stage insist that a firm be employed to make test borings at

the site. In some localities there is so much variation in soil conditions that data available on nearby property may not apply on the proposed site. The cost of test borings is a minor consideration in comparison with the amount that may be spent in extras, or the amount that might have been saved, had the exact condition been known. Therefore, the engineer should insist on test borings in all cases where major structures are being planned.

The engineer should inform himself as to what type of foundations have been used for other buildings near the proposed site. He should have an opinion as to what type is best suited for the proposed building on the proposed site. If more than one type could be used for the case in hand, he will be asked for approximate comparative costs.

The engineer must be informed as to the legal responsibilities of the owner of the proposed building in regard to adjacent buildings. It may be that excavation on the proposed building is to extend deeper than the foundations of adjacent buildings. Will this lead to settlement of foundations of adjacent buildings? If so, who pays the costs of necessary shoring and underpinning of adjacent buildings? The conditions found on adjacent property must be considered in deciding on the type of foundations to be used for the proposed building.

These and many other questions require answers as a part of the preliminary service of the engineer. Sometimes the engineer has a little time for hasty, approximate designs to answer some of these questions, but many questions may require an immediate answer during a conference. Answers to such questions, and answers that will be approximately correct, can be given only by the experienced man. In the light of such questions and such service as must be given by the engineer, one realizes that good service on structural design must combine technical knowledge with experience, judgment, and common-sense.

DEFINITE DETERMINATION OF CONSTRUCTION

Type of Structural Frame—Structural Steel or Reinforced Concrete. Usually, perhaps, the type of structural frame will have been determined during the first stage of progress. It may be that the engineer's experience has been such that he was able during the prelimi-

nary conferences to advise with assurance that one or the other type should be used, and to give sufficient reasons for his opinion so as to settle this question without further investigation. However, the owner may have a definite preference on which he may insist, even though the other type may have equal merit for the project. This is particularly true in reference to the preference of some owners for a structural steel frame.

Occasionally, however, the problem requires further investigation. Possibly either type could be used without sacrifice in architectural requirements, but possibly with some difference in lay-out for maximum economy in one or the other type. Some tentative designs may be required for a typical section of the floor together with supporting columns and cost estimates, for comparison. Often these cost comparisons are checked with estimates by a prospective contractor, or one who has been given a tentative contract. The time spent on such work at this stage of the design is very much worth while, as the settlement of this question will later mean a definite saving of time and money for all concerned.

Type of Floor Construction. The type of floor construction may have been tentatively settled at preliminary conferences, but the final decision is usually left for further investigation. The type is often involved with the decision as to type of frame. However, even though the decision as to the frame has been made, there are often several possibilities as to floor construction. It may be largely a question of economy. The engineer will then usually pick a typical floor section that promises a good average condition, and then prepare designs and make cost comparisons. Here he may also ask for cost estimates by a contractor.

In considering cost comparisons for type of frame and type of floor construction, it should be borne in mind that, while some one type of construction may have proved economical on another similar building, factors which must be considered may give different results on the project in hand. Even though the size of panels and height and use of the building are the same, such factors as availability of materials, market conditions, conditions at the proposed site, speed of construction, and the experience or prejudices of the probable contractors must be considered. The prejudice of the contractor is a

factor which the engineer must weigh, and he must not take the opinion of one contractor as conclusive. This is evidenced by the results in one case I know of where four alternates were given for one building. The designs were very comprehensive for each alternate, and all were made by the same engineer, but of the four low bidders with total bids close together, no two placed the four alternates in the same sequence with regard to economy. The sequence favored by one contractor was reversed throughout by another one.

Type of Foundation. The type of foundation, also, may have been settled during the preliminary service. It may be, however, that more definite information was required before the type could be settled. From test borings, the experienced man can usually reach a decision as to the type of foundation that should be used. Along with soil conditions at the site, consideration must be given to other factors, such as foundations of adjacent buildings, and the relation of elevations of proposed excavations to the foundations of adjacent buildings. If there is danger of settlement of adjacent foundations, the design must minimize such settlement, and cause as little expense as possible in shoring or underpinning of adjacent buildings. Even though the law may be such that the expense of such shoring and underpinning will be borne by the adjacent property, it is the duty of the engineer to design the foundations so as to minimize such expense.

Consideration must be given to methods of shoring, and to trenching of walls. The details for this will, of course, come later in connection with design and plan of the foundation, but the general scheme must be outlined in connection with the decision as to type of foundation.

DESIGN AND DESIGN DRAWINGS

With the type of frame, type of floor construction, and type of foundation settled, the design and design drawings can proceed. The several steps of procedure do not necessarily follow exactly in the order here indicated; some of the steps will be carried on simultaneously.

Typical Floor. The design of the typical floor (or floors in case there is more than one condition) will come first, however, since the

typical floors represent the major portion of the floor framing for the building. Other floors will, so far as is possible, be made similar to the typical one. Extreme care should thus be used in the lay-out and design of the typical floor, keeping in mind not only safety of design, but economy of construction. Usually there are a number of panels alike on the typical floor and any economy in one is multiplied just as many times as the condition repeats. Thus, if close designing saves five pounds of structural steel per foot in a beam with a span of 20 feet, and there are 10 such beams per floor and 20 floors alike, the total saving amounts to ten tons. The same principle applies to savings effected in pounds of reinforcing steel or in cubic feet of concrete. If considered in terms of cost per square foot of floor, it is noted that a saving of five cents per square foot may mean $25,000 to $50,000, or even more, depending upon the floor area. Of course, the refinement in design computations should not be carried too far, since it is foolish to spend five dollars extra in time, to save one dollar's worth of material in a beam or panel that occurs only once. An increase in labor cost of construction may overbalance the saving in material.

It must also be borne in mind that safety and proper design are of first importance. Economy must not be attained by skinning. The floor capacity must provide for all dead load plus the specified live load, and code stresses should not be exceeded. Careful and close designing without skinning, however, is certainly justified on this typical floor construction.

Column Loads. The design of the columns is of maximum importance in regard to safety and accuracy. The design, however, is almost equal in importance to that of the typical floor with reference to economy.

The column loads should be carefully figured and checked so that there is no question but that the right amount has been figured, neither too much nor too little. The computation of load on typical floors is of greatest importance, since any error in this floor load is multiplied many times in the total load on lower column sections. All loads should be included so that the designer who picks the column sections can design the sections closely with the assurance that the scheduled load is correct. He will know then that for any section

of capacity slightly under the scheduled load the overstress will be small.

Approximate Sizes of Columns, Girders, and Trusses, and Approximate Requirements for Wind Bracing. The architect will require information regarding size of columns, girders, and trusses as early as possible in the progress of his drawings. Approximate sizes may have been given to him during the preliminary stage. With the design of the typical floor well along and the column loads determined, the engineer can confirm such preliminary information and give sizes more closely. At this stage of progress, the designs for all trusses and girders are usually started, and later followed through to completion.

Reliable information on structural requirements must be furnished to the architect as early as possible so that his architectural working-drawings and his structural drawings can be developed simultaneously. Throughout the progress of the design drawing, there should be interchange of information; questions must be settled by the engineer for the architect, and by the architect for the engineer. Questions will also arise with reference to mechanical equipment, and these must be settled among the architect, the structural engineer, and the engineer for mechanical equipment. The work of either of these is involved with the others and the careful co-operation of all parties is required at all stages so that when their respective drawings are completed for bids the several sets will be in accord.

Glaring discrepancies in the several sets of drawings indicate poor co-operation and lead to difficulties involving extras and misunderstandings. To say the least, such discrepancies in drawings that are supposedly ready for bidding mean additional expense to one or all of the parties concerned in the preparation of the drawings.

This part of the design work may be comparatively simple when only a few girders and trusses are involved, but on a complicated building lay-out may mean considerable work. On several building designs with which I am familiar, a great deal of work was necessary in roughing out the designs for trusses, girders, etc. One such, a building 100 by 130 feet in plan and thirty odd stories in height, had only one interior column continuous from foundation to roof. All other columns were offset on girders and trusses some place in the

height—some at the first, second, third, or fourth floors; and others between the twentieth and twenty-fifth floors. Each case had to be laid out, designed approximately, and considered in relation to architectural requirements. Another building involving "air rights" over a railroad right of way, with certain definite locations for columns, required a vast amount of design work at this stage. More than usual accuracy was required in rough design in order to fix overall sizes that became a part of the "air rights" agreement which had to be drawn up and signed by the time the design drawings were complete.

The requirements for wind bracing must be definitely determined at this stage, so that such allowance as may be required can be made in architectural drawings. The engineer will, so far as possible, endeavor to work out his bracing to fit the scheme desired by the architect, but, in complicated lay-outs, or in the taller buildings, it is often necessary to make concessions in architectural lay-out. These should be determined before the architectural drawings are too far developed.

Other Floors and Roof. The designs for other floors, and for roofs, will be started soon after the start of the typical floor. Good designs of these other floors will have framing like the typical floor wherever conditions are the same. The designers of these other floors should check with the design of the typical floor framing so that the framing of all floors is consistent. Constant touch with the architect is required in the preparation of the designs of these various plans so that structural and architectural plans may match. It can be said further, in reference to co-operation, that the structural engineer must not only co-operate with the architect and the engineers concerned with mechanical equipment, but he may in self-protection have to insist that the others co-operate with him and supply him with needed information at the right time during the progress of his design.

Foundations. Frequently the construction of the foundations is to start before plans of the entire building are complete, and in this case foundation plans are required as early as possible. Whether this is so or not, the design of the foundations will usually be started as soon as column loads are available. The design can then proceed as

rapidly as desired. Much more than the design of the individual footings of spread, pile, or caisson is involved.

As stated in connection with determination of type of foundations, methods of procedure in meeting conditions of adjacent property will have been considered, and now the designs must be made and shown in detail on the drawings. All retaining walls must be designed. Where more than one basement is to be excavated, the design is involved with practical construction methods, shoring, and underpinning. Though the contractor is responsible for the use of construction methods which insure safety of adjacent buildings, it is incumbent on the engineer to design so that safety, practicability and economy are assured. A good design and drawing will enable the contractor to estimate his costs more closely, and this will be reflected in his bid. There is perhaps no part of a structural design more important than the foundation.

Column Sections and Column Schedule. With the column loads carefully determined, the column sections can be chosen with confidence. The designer must pick the sections with regard to the framing of the various floors, making allowances for bending due to eccentric loads, etc. The connections at various levels must be kept in mind, as the shape of the section must be such that proper connection can be made for trusses and girders.

Here again, economy is an important consideration. A saving which may seem negligible in a single column acquires greater importance when extended to a hundred columns.

The schedule of column sections can now be made. This must not only list all material required, but must give full information for heights of stories, points of splicing, and such details as are necessary for complete fabrication.

Trusses and Girders. The approximate designs for trusses and girders previously made must now be refined, designs completed, and design details made to show all material required, together with requirements for splices, proper joints, and connections. All important connections, and any unusual conditions, should be drawn up in detail so that the fabricator and erector will know what is required. All loads, stresses, and reactions must be shown. The engineer must

be cognizant of shop practices, standard details, and methods of erection. While no detail dimensions for fabrication need be given, the designer must have such dimensions in mind, so that he knows that details of connection, splices, or joints can be made as indicated.

The amount of design work required in this step depends, of course, upon the number of trusses and girders, and upon the spans and load to be supported. I have known a number of jobs on which designing this part of the work required more time than all the rest of the building. Safety, accuracy, and practicability are the main considerations here, although care must be used to see that material is not wasted and that details are not too expensive.

Design and Details for Wind Bracing. Although the general scheme for the wind bracing has been previously outlined and the computations for wind stresses made simultaneously with designs of floor framing and columns, the final design for sections and details is usually left until the general floor framing and column designs are well developed. The designer of the wind bracing must trace through all plans and see that the sections called for are those required for combined gravity and wind loads. He must also see that any necessary modifications in column sections, due to combined loading, are made in the column schedule.

A great deal might be said about wind bracing. There are various methods of design. Most of these have some merit. None of the several methods gives results that are fully correct. Experience and judgment are large factors in the design of any adequate system of wind bracing. The designer can only insure that bracing is provided that will make a building safe for the expected wind load in as economical a manner as possible.

Many high buildings, built with almost no reliable bracing, are still standing largely by reason of the shelter and propping provided by adjacent structures. It is by no means certain that a building with bracing of only half the capacity required by the best practice would be wrecked in the maximum wind. We had examples of this in Miami, Fla., some years ago. We know that a building insufficiently or improperly braced may, while in no danger of falling, suffer some damage in cracking partitions in every wind storm, and that its

value to tenants may be seriously diminished by excessive motion under wind. There are also many buildings in which the material and the labor were not used effectively.

With the higher buildings we are now constructing in constantly increasing numbers, it is imperative that proper bracing be provided in as economical a manner as is consistent with good practice. Experience and judgment must be reinforced by a higher order of analytic ability in the design of wind bracing than in any other part of the structure. Great economy is possible within the limits of safe design.

Completion of Drawings for Bids. Little need be said here in reference to this step. It is assumed that the design is well along toward the finish and that all necessary information as to material, details, and dimensions is now being incorporated in the drawings. It is to be noted that considerable detail of spandrel sections for proper masonry support may be necessary, and this requires careful co-operation with the architect. Here again, experience and knowledge of construction methods are large factors in producing a set of plans that give sufficient information, but no more than required for intelligent bids and proper construction.

Final Checking of the Design and the Design Drawings, and Cross Checking of Structural Drawings with Architectural Drawings, and with Drawings for the Mechanical Trades. A well developed set of structural drawings will have been cross checked, with the architect, the mechanical engineer, and the electrical engineer during the progress of the design and drawings. The design will have been checked as the computations proceed. Good designers will cross check their own computations as they make them, so that the number of corrections necessitated by this final check should be few. However, slips will occur and all these should be caught before contracts are signed; so that, if necessary, adjustments can be made to avoid extras, and so that, when contracts are signed, the drawings may be immediately available to the contractor for construction purposes. Generally this checking is started after the drawings are printed for bids, and it should be completed by the date set for receiving bids.

SHOP DRAWINGS

The engineer must see that his design is carried out. He must, therefore, examine all shop drawings for structural steel to see that the sizes are in accordance with his design drawings and that design details have been followed. He must examine the details of all connections, to be sure that they are adequate for the loads or stresses. The responsibility for detail dimensions lies with the structural steel fabricator, but the engineer must see that the details are in accordance with plans and specifications and in accordance with good practice. The responsibility of the engineer extends also to the shop drawings for other materials.

SUPERVISION OF CONSTRUCTION

Often the engineer is not commissioned to superintend the construction. Nevertheless, both his own interest, and his proper service of co-operation with the architect, require a certain amount of supervision. He will visit the job as often as may be necessary during the progress of the construction to see that the work is carried out in accordance with plans and specifications. It may also be necessary for him to supply additional designs or design details to meet job conditions.

The engineer might learn that a job for which he has design responsibility only, is being erected very carelessly, so that the factor of safety on which he relied is being seriously diminished. He should then take such steps as are open to him to correct the contractor's methods. If he must act through his client (the architect) and protest brings no results, he may still approach the owner, if the case is very serious and, failing there, go to the city building department. He is responsible for the construction of anything he has designed, whether he is paid for it or not, and for the sake of his own reputation he should exercise his authority.

It would be better if, on important structures, the engineer were commissioned to superintend the construction of the structural parts. In such cases, he would have one or more men on the site at all times co-operating with the architect's superintendent and reporting daily to the engineer the progress of the work.

Conclusion. In conclusion, I have very little to add. No direct reference has been made to questions of ethics in the practice of

structural engineering. Ethical practice is, of course, a requisite of proper service. A consulting structural engineer is employed to design with materials and processes for the particular problem in hand. He must be of independent mind. To be so he must be free from all connection with the profit side of the manufacture or sale of any building material or process and also free from the influence of those who are. The engineer should not accept commissions for partial service. His commissions, service, and responsibility should cover all structural parts of the project. I have attempted to point out some of the many questions that must be answered and some of the problems that must be solved by a structural engineer during the various stages of a design for a building. I know that the thought I have given recently to the subject in the preparation of this paper has been useful to me, and I hope that what I have said will be useful to all of us in realizing and renewing our faith that men of slight experience and technical training could not possibly take the place of the engineer with years of experience in producing safe and economical structural designs.

DISCUSSION

C. N. Haggart, *Chairman:** Mr. Brown could not give us this paper without having a very considerable amount of experience in building and designing such structures and in collaborating with other builders. We are all very much interested in the paper, I am sure. It is a good thing to have brought before us repeatedly the thought that the larger and higher buildings should be designed by men of mature experience.

F. S. Merrill:† I want to emphasize what Mr. Brown has said regarding the necessity of having experienced men design important structures. We see a good many cases in bidding on various kinds of work where the experienced man has saved the entire cost of his design on a structure that is so economical that it can be built very cheaply.

So often, contractors with only a handbook knowledge design something which is, you might say, theoretically economical, but

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doesn't work that way. They will save ten pounds of materials, but will have to make extra drawings costing many times that amount. An arrangement of steelwork is often shown which involves expensive shop work, with little or no duplication, where the work could just as well have been simpler and cheaper. We feel that, in a structure of any magnitude, it is very important to have experienced engineers; the work that they do is of very great importance to the whole project.

T. D. Mylrea:* In all the papers presented to-day, one thing has been very noticeable—that is, the emphasis on progress in better ways of doing things. The time-honored method of squelching a new idea by stating that it is not "standard" practice has suffered a severe shaking up in the past few years. New methods of rolling have made the structural designs of a few years back almost obsolete. Careful thought on stress distribution has been followed by a general revision of the specifications for the use of structural steel in building work by the American Institute of Steel Construction. The American Concrete Institute is at present engaged in a similar task, and several of our large cities are entirely rewriting their building codes.

This insistence on the better use of material makes it necessary to be more certain of our theoretical analyses and to develop such methods as will give accurate results with a minimum of labor. It was my pleasure to point out one such method to the members of this Society a few months ago, and in conversation with Mr. Brown this afternoon I find that his firm has been active recently in simplifying the process of designing for wind stresses in tall concrete structures.

Structural design of buildings of any size is fast becoming a fine art, and fully justifies the answer given by Mr. David Coyle when asked "How do you design wind bracing?" His reply was "How do you play a violin?"

I feel sure that each of us has benefited by listening to these papers.

*Professor of Building Construction, Carnegie Institute of Technology, Pittsburgh.

FOUNDATIONS*

By Carlton S. Proctor†

The most difficult part of the preparation of this talk was in the choice of a topic, since the field of foundation engineering is so large that in a single talk very much of interest must be omitted. This talk might have covered bridge foundations, in which case only the high spots could have been covered in a single talk; or dams, or tunnels, or soil mechanics, or many other features of interest. But I have chosen a rather rambling treatise on foundations of buildings. I shall attempt to give you an outline of methods of attack of a foundation design with a sketchy discussion of the particular foundation problems of a few large cities. Then I shall try to sketch for you the very interesting and comparatively recent transition from pneumatic to open installations in down-town New York, with a description of some of the most unusual and daring jobs in that city and a few jobs elsewhere, and close this talk with a series of slides intended to review quickly the points I hope to make fairly clear in the talk.

The principal reason for segregating the design of difficult and important foundations from the design of the superstructure is that the foundation design must be approached with an absolutely open mind, to produce the best results from the standpoint of stability and economy. Similar superstructural problems are met time and again, whereas the subsoil conditions controlling foundation designs are never the same at two different sites. The fundamental prerequisite for the correct approach to a difficult foundation problem is an unprejudiced attitude in the conception of the design.

Of all the foundation failures with which I am familiar (whether structural or economic failures), in virtually every case the difficulty can be traced to an attempt by the engineer to find a similar condition where he could apply an established precedent by using a previously successful design; or where he has been influenced by a salesman for a contractor specializing in a particular type of installation.

Considering only those localities where foundation conditions are bad—such as in down-town New York; the old stream beds in

*Presented November 5, 1931. Received for publication November 28, 1931.
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up-town New York; and such cities as Cleveland, Montreal, and Detroit—I know of few cases where the method of leaving the decision as to difficult foundation development to the foundation contractor, or to an engineer insufficiently experienced in foundations, has produced a safe and economic result. It is a fact that where the subsoil materials do not lend themselves to a cheap and apparent support of the structural loads, or where real-estate values and zoning laws demand the production of maximum economic basement space, the correct solution is obtained only after careful and thorough studies of foundation types in conjunction with the economics of the uses of basement space by the particular tenant.

First, a comparative study reduced to accurate estimates of cost and time for each method or combination of methods available, produces a base minimum cost, with a base substructure space production. One solution will show a minimum cost at one basement, while another scheme is cheapest at two basements. Frequently we are instructed to produce a design providing only one basement where the plot is nearly square, the column loads heavy, and the cheapest and most adequate solution is piers extending to rock; and where the cost of pier installation so much exceeds that of general excavation that the net cost of two basements is less than that of one basement.

Navigable water is a controlling factor in the growth and development of cities, and the heavier structures requiring the heaviest foundations are, therefore, frequently on the banks of rivers and lakes and often at the outlets of rivers. Rivers chose their locations where they could most easily cut a channel, and broke through at their outlets where the soil offered the least resistance. Frequently a river meandered over quite an area in its search for a channel and for an outlet, first cutting away the original soil and then depositing the soil burden which it was carrying in suspension. It is therefore logical to expect deposits of silt, mud, and clay (those materials which afford the poorest foundation supports) at locations where heavy structures require the firmest foundations. Over Manhattan Island this type of soil deposit is found only within a block or two of the two rivers. Elsewhere, an excellent bed-rock is reachable over nearly all of the island. In many of our larger cities, however, water-borne deposits cover considerable areas, and it is frequently impos-

sible to reach a material which is capable of supporting the loads of New York's highest sky-scrapers.

Subsoil conditions are not the same in any two localities. In Philadelphia the terrain overlying bed-rock is somewhat similar to that in New York; but, whereas, the bed-rock in New York has been scoured by glacial action so that the disintegrated soft rock has been removed, and protected against further disintegration by the glacially deposited blanket of hard-pan, the glacial movement did not reach as far south as Philadelphia, and in that city we find the bed-rock soft and disintegrated to considerable depths. The absence of glacial scour below New York presents a considerable problem in foundation treatment throughout many localities in the South, because in some cities, of which Atlanta, Ga., is a notable example, the residue of bed-rock disintegration has left a subsoil material far less dependable than an ordinary sand deposit, and such disintegrated rock is frequently not only valueless as a supporting material because of its soft, slippery consistency, but difficult and expensive to remove because of its considerable depth.

In Albany, N. Y., and in Cleveland, bed-rock is generally of such depth below grade as to be unreachable and the deposits over bed-rock in both cases consist primarily of clay. In Albany the clay is so highly saturated that in many localities, particularly on Capitol Hill, the addition of any load to the soil starts the flow of water from the voids in the clay structure, so that a relatively lightly loaded foundation on this material will usually continue to settle for a considerable period of time. In Albany (because the flow of water under loaded areas creates supersaturated areas adjacent thereto which result in a sliding movement of large bodies of the clay) the problem became so serious that it was necessary to devise an entirely new and radical type of foundation to meet this condition. Briefly, it was necessary to make a cellar excavation which would remove from the area of the site a load of clay equivalent to the load over the area of the site. The entire substructure must be designed as a series of interconnecting two-story Vierendeel trusses.

The Federal Reserve Bank and the Barclay-Vesey Telephone buildings are outstanding examples of the value of comparative studies, for in each case not only comparative types of foundations were analyzed, but substructures producing from one to six base-

ments overall and varying parts of the area were carefully considered in a study of their costs and economic uses and values. The very first consideration for either of these foundations was one of straight economics. Both were located on valuable ground where height was restricted. As the ground value increases, the amount of space created within the building should increase, and increased space could be economically obtained only below ground. The first requirement was, therefore, a determination of the cost of creating and servicing various amounts of basement space. For each design, many studies were made which proved that the unit cost of such space steadily decreased as its volume increased, and that the entire space to bed-rock could be obtained at a low comparative unit cost.

The proved type of foundation for a given building should not be accepted as economically the best type for a similar building with similar subsoil conditions, because each new major operation should develop newer, cheaper, and quicker methods, at the same time taking advantage of those previously developed. For example, prior to the Federal Reserve Bank foundation it had been taken as a matter of course that the stress in the timber temporary cross-lot bracing system must be developed by the inward movement of the coffer-dam walls, and the efficiency of the bracing system was generally only about 50 per cent., since varying stiffnesses of coffer-dam walls precluded the possibility of accurately determining the amount of stress which would be brought to each stick. Experience had taught that when a bracing system was designed for more than about forty tons per stick, failures resulted, requiring emergency additions to the system. The Federal Reserve Bank's lowest basement was about twice as deep below grade as that of any previously constructed, so that by bracing according to precedent not only would the resulting forest of timber have caused very slow and expensive work within the coffer-dam, but the floating Mutual Life building across Liberty Street might have been damaged seriously. The bracing design was, therefore, based on the use of timber at its known strength of nearly eighty tons per stick 12 inches square, and the first field operation was to set up a full-size testing laboratory across the lot. Experiments demonstrated that it was impossible to wedge a timber by previously employed methods to more than 40 tons, because one or two wedges were, at the instant of driving, carrying such high intensity as to

split or destroy the stick. A double wedging system, when driven in these experiments, pushed the walls out, so a horizontal system was driven up to develop 40 tons, and, when the excavation had been carried to the level where the external stresses equaled this amount, the remaining 40 tons were introduced by vertical wedges. Since that date, this detail has been standard practice, reducing temporary bracing costs and the damages to streets and buildings, because it is now no longer necessary that coffer-dam walls move in. However, on this same job the lateral pressures were so enormous that it was necessary to support the coffer-dam permanently through heavy steel struts (or horizontal columns) and, for the same reasons which controlled the timber design, these struts were completely stressed before releasing the timber.

These identical problems were faced in designing the substructure of the Barclay-Vesey building with a deeper basement, and these solutions having been thoroughly developed were further improved. Instead of placing the permanent steel bracing after the completion of general excavation, the excavation was halted when two-thirds of the way to rock, and the permanent steel struts installed and supported on temporary piles. Instead of stressing the permanent struts in advance, by the slow and expensive hydraulic jacking system used on the Federal Reserve Bank, steel wedges were introduced by impact from steel rails in less than a tenth of the time, the amount of stress being controlled by micro-caliper readings made feasible and improved on by our experience on the Federal Reserve Bank. The installation of the permanent bracing system to act in conjunction with the temporary bracing system saved half of the temporary bracing.

Starting our studies for a foundation design, we must first consider the boring samples and records, in conjunction with the structural requirements of the building to be supported and the economics of the foundation problem, which must include ground value, zoning restrictions, value of surrounding buildings, cost of production of superstructure space, and the immediate or probable value of subgrade space for bank vaults, cafeterias, building utilities, storage, and even office space. First, a comparative study must be made to determine accurately the cost and the time of installation for each available method or combination of methods for foundation design, and from

this a minimum base cost is obtained with a base substructure space production. We are too often apt to consider the time element of an installation as of secondary importance to, and as separate from, its cost. Actually, they are frequently one and the same thing, and sometimes a saving in time has important financial value out of proportion to the cost of the work. Usually an office building must be ready for renting for occupancy at the first of May, and failure means a year of difference as to rentals and revenue. The first year's rentals received from the building at 40 Wall Street were so enormous that methods of installation were compared solely as to their time requirements, and it was the time requirement which led to the development and successful installation of a type of foundation which revolutionized opinion on foundations in down-town New York. On the New Orleans bridge, where bonds must be sold for the entire project prior to beginning the work, the daily interest charge on bonds is a controlling factor.

Now the primary function of a foundation is to provide safe and adequate support to a structure against downward and lateral movement, and the function of the foundation design is also to provide the maximum economy consistent with safety by the most workable and practicable methods of installation. The soil on which a foundation may rest will vary from a solid bed-rock capable of supporting virtually any load which we are able to bring to it, through to peat, silts, and soft clays which are sometimes in process of settlement and consolidation under the weight of their own overburden of soil, and frequently incapable of supporting any additional load. The methods employed to install the foundations to the depths required to reach satisfactory supporting material, without incurring or permitting movement or loss of soils from adjacent areas, must be carefully selected from the many available, and frequently must be specially developed to meet the specific conditions.

Consider an average case of a heavy building on expensive ground where bed-rock is at considerable depth. Possible foundations for this building include:

1. Spread footings, or reinforced concrete mat, where the mat may be of a heavy solid construction, of articulated or waffle type, or of the Vierendeel truss type which utilizes as a part of its design the basement walls, floors, and columns.

2. Any of the numerous types of piles, including friction piles (either precast or cast in place) and point-bearing piles, of which the concrete-filled steel tube is a common example.

3. Deep piers to hard-pan or rock, installed by either open or pneumatic methods.

4. A permanent, reinforced-concrete coffer-dam (either open or pneumatic) on the perimeter of the site.

A selection from this large number of available types is never a matter of haphazard choice and frequently not even a matter of the best judgment, but is the result of careful studies which consider every factor entering into the problem. Where the selected design involves (as it usually does in down-town New York) five to seven stories of basement space, the principal problem becomes not that of supplying vertical support to the structure, but (1) the installation and maintenance of adequate lateral support through bracing of the exterior foundation walls, since these walls must act as a coffer-dam against enormous outside pressures, including hydrostatic head, weight of submerged materials, and surcharge of adjoining structures; and (2) the very important matter of adequately supporting and underpinning the adjoining buildings having foundations which are not carried to rock, and assuring against movement of the streets. Tremendous damages might result from the movement of one of the metropolitan streets if such movement resulted in the breaking of any of the utility lines installed in every down-town street. The foundation design should, therefore, include the design and specification of lot bracing, underpinning, and shoring, and the engineer who attempts to evade his responsibilities by leaving decisions as to types, methods, and amounts of bracing, underpinning, and shoring to the foundation contractor under a specification or contract paragraph, passing the responsibility to the bidders, is, to say the least, remiss in his duties and is at least morally and professionally responsible for failures or accidents which may result.

Until comparatively recently, every one familiar with the subject considered that a foundation for a building in down-town New York must be installed under compressed air. In fact, it was commonly said and written that the development of adequate pneumatic methods had made possible the sky-scraper of New York.

The first pneumatic caisson installation for a building foundation was for the old Manhattan Life building at 66 Broadway. This installation consisted of a working chamber with timber sides and roof and superimposed brick pier. This type was superseded by the steel working chamber and brick pier, then the steel working chamber and concrete pier, and finally the development and patenting of the concrete working chamber and monolithic concrete pier. My partner, Mr. Moran, patented and developed these features, which gave quite an impetus to deep foundations and higher buildings. In the early stages of pneumatic development, the caisson was simply a pier to carry the support of each column to rock or hard-pan; then the pneumatic joint was developed which made possible the pneumatic coffer-dam wall surrounding a deep cellar. The columns on the perimeter of the site alone were supported on caissons—two or occasionally three columns on each rectangular caisson—and the small spaces between the caissons were filled with concrete under compressed air.

The desire for greater economy and the temptation of the owner to select a cheaper though less secure type of foundation led to the development of open methods for deep coffer-dam installation.

In 1927 the first open foundation installation was made in downtown New York, and to-day it is only the exceptional job which is designed to be installed under air pressure. Unfortunately for the best interests of the owners, and for the best development of the profession, in nearly every city there is a definite preconceived idea that the type of foundation which has been used in that city for many years is the best and most economical, and frequently the idea is maintained that it is the only type of foundation that can be employed in that city. Detroit has its own type of foundation pier; Chicago has the well known Chicago caisson; Washington for years has been wedded to a particular type of pile; Boston has its own particular type of caisson or pier, and so on for each of a number of cities. New York was determined that nothing was safe except pneumatics. In 1922 we designed the foundations for the Bank of America, to be installed by open methods. The contractors refused to figure open methods and the only bids were on pneumatic work, so this job was a compressed air installation. Between this building and the Harriman building, we made several efforts to obtain bids on what we

believed to be safe and efficient open design—one which would control ground water and quicksand against flow and loss and produce a safer foundation from the standpoint of its effect on surrounding property, as well as a very much cheaper foundation.

We felt that the proper treatment of quicksand was through underdrainage and prevention of movement. This was comparatively easy to explain, but it was impossible to convince the building public. Unfortunately, soon after the Bank of America installation, a contractor attempted open installation in New York, on the theory that there was no justification for the common fear regarding quicksand, but that one with sufficient nerve could overcome it. The results of this contractor's experience were costly and disastrous, and as a result of his experiment the idea became more firmly rooted than ever that down-town New York must stick to compressed air.

Fortunately, when we were employed for the Harriman building at 39 Broadway, we were compelled to provide a foundation design which would fall within a budget allowance which the general contractor had established for this building on the statement of a foundation contractor, that a certain type of pile could be installed to reach a bearing on bed-rock. Our investigations of the subsoil borings disclosed a relatively thick layer of heavy boulders at a considerable depth above rock and we became convinced that the installation proposed was impossible. In fact, we refused to continue on that basis, and offered as a substitute, which would meet the budget allowance for foundations, an open type of pier installation to bed-rock. Again no foundation contractor would figure on this method, so we sent one of our own inspectors to the site with a gang of laborers and installed an open pier to rock in the deepest section of the lot. The usual foundation pier is immediately filled in with concrete so that any small leakages of water and inflow of soil will be of no consequence, as it would be plugged immediately by the concrete filling in the pier. This operation was installed under the worst conditions because the old buildings were being wrecked while this pier was being installed, and it was necessary to seal the pier absolutely so that it could remain open and skeptical bidders could go down into it and see for themselves the method employed in its installation. As a result, bids were obtained on the method proposed and a thoroughly satisfactory foundation was installed. Notwithstanding this experi-

ence and demonstration, foundation contractors owning large amounts of pneumatic equipment continued to deny the safety and practicability of this type of installation. Prior to erection of the Harriman building only a few contractors ever figured on work in downtown New York, a large majority being content to work elsewhere and refuse to figure on foundations involving operations through quicksand.

This job was followed very closely by a similar open installation for the International Telegraph and Telephone Company, and, notwithstanding these two marked successes, when the first open cofferdam installation went out for bids, the contractors refused to accept the responsibility for the success of this method and again advised the use of pneumatics. Again an open operation was a complete success, with no recordable movement of adjoining buildings or adjacent street structures and at a saving of about 40 per cent.

These experiences clearly demonstrated the fact that, when properly designed and carefully supervised, great economy of time and cost could be safely effected by open methods in the district which for years had been exclusively the field of pneumatic contractors. Since then, still greater knowledge of open methods and means of unwatering soils has resulted in previously unthought of trespasses into compressed-air territory.

This departure from compressed air has not stopped, because while open work properly executed is cheaper and quicker, the new open methods are in process of radical improvements providing greater economy with no sacrifice of safety either to the building or to adjacent structures. We are now designing foundations for three important structures located where even last year nothing but pneumatic methods would have been considered. In one of these two cases the operation will be open. In the other two, unwatering operations will permit of open foundation-pier installation either all of the way to rock or so close to rock that only very low air pressure will be necessary to complete the operation. This may be contrasted with the maximum allowable air pressure of 50 pounds required if sinking operations were handled from existing water-level.

The trend in design of modern building foundations can be illustrated by reference to proposed foundations for the Bell Telephone Laboratories where alluvial silt—worthless as foundation material

for the support of building loads and frequently involving expensive removal—is in this case ideally utilized to permit of an installation at a very considerable saving in cost over that which would be required if the silt blanket were not present.

The impermeability of certain alluvial silts to the flow of water was demonstrated in the foundations for the Wilbank telephone exchange in Montreal, where a silt deposit 50 feet thick overlaid a fissured and faulted limestone bed-rock, and where all methods of surface drainage had failed: The material "boiled" as fast as attempts were made at excavation, and when I was called into consultation arrangements had been nearly completed for conversion to pneumatic installation. This change would have resulted in more than doubling the cost of foundations, and I was asked merely to approve the prevailing certainty that no other method was possible. When I first walked on the job I saw a laborer, who had sunk into the silt above his waist, being pulled out by a derrick. In the attempts which had been made at excavation, I was surprised to find large boulders near the surface of the silt at nearly 50 feet above rock, and an examination of the boring records indicated boulders throughout the silt formation. The presence of these boulders convinced me that at the time this formation was being laid down there must have been vertical drainage and that the silt formation must then have been of a compact nature, because if the silt formation had originally been in the condition in which I found it, the boulders would have settled to the bottom and have been found immediately overlying the rock. The presence of the Lachine Canal in the immediate vicinity afforded a possible explanation for a radical raising of the water-level and the saturation of the material. I immediately asked that a dredging caisson be sunk to rock, pumping water into the caisson to maintain a higher head than that outside to prevent the inflow of silt during the dredging operation. When the caisson reached rock, a two-foot "tremie" seal was placed and the caisson pumped out, after which a sump was drilled through the "tremie" seal and into the rock to a depth of eight feet. The fissured and faulted condition of the rock caused a considerable flow of water into the caisson as soon as the "tremie" seal was drilled, and pumping was necessary to excavate the rock to the desired depth. After the excavation of this sump, a six-inch "pulsometer" was installed, and, after 24 hours of pumping, the

silt surrounding the caisson for a distance of 25 feet was dry on the surface. This original sump was installed at the center of the site and immediately thereafter four other sumps were installed in the corners of the site. Pumping from these sumps reduced the water-level so rapidly that the material became firm and hard, permitting excavation for all piers to bed-rock by poling boards or horizontal sheeting methods.

When we were called in on the foundations of the Greater Penobscot building they were in real trouble, because this was then the biggest building in Detroit and the open caissons were of considerably larger area than had previously been used, resulting in the floor of the excavation blowing up and the caisson flooding as the caisson approached rock. This type of caisson was developed to meet the situation and at the same time retain the economy of the Chicago well method which had previously been successfully employed where the areas were smaller. The caissons were stopped on the so-called Detroit hard-pan by carrying the Chicago well to a depth such that sufficient clay remained above the hard-pan to resist the hydrostatic uplift by arch action, and decking over at this level to convert into pneumatic installation. This resulted in a most economical treatment, constituting a type of installation which has been generally used since, and will undoubtedly be used hereafter for Detroit's high buildings.

No doubt many of you have had an opportunity to inspect the very interesting foundation work now in progress at the Pittsburgh Federal building at Grant Street and Seventh Avenue. The foundations for this work are very deep and are being built by the open-trench coffer-dam method, in spite of the fact that experience on one foundation job directly across the street, which was done partially with compressed air, might have dictated the use of air on this job. The Federal building is approximately 530 feet long and at the north end is about 180 feet wide. The basement construction includes a single basement except at the north end, where a very deep basement is provided to take care of a power-plant and mechanical services. Soil borings indicated shale rock above the normal basement level at the southeast corner of the building, while at the northwest corner shale drops to a level of about 75 feet below the street. Two problems faced us in the design of these foundations:

1. To decide upon a safe and economical method for supporting the entire building on bed-rock regardless of its depth.

2. To support the walls surrounding the basements until such time as the superstructure should be built to provide floors and steel-work which would support the walls.

A thorough investigation of soil conditions and records of nearby jobs convinced us that the foundations could be installed in the open. The final design provided for a double sheeted trench entirely surrounding the site, excavating the sheeted trench and building the concrete walls complete before removing the general excavation within the lot. The sheeting was supported in the trenches by horizontal H-beam walers and cross struts. The sheeting was driven around the lot in a single drive up to lengths of about 58 feet, except across the north end and for about 150 feet on Grant Street, where it was necessary to drive the sheeting in two lengths. For the normal basement, a large amount of general excavation was removed in the center of the lot, leaving sloping earth berms to support the side walls, and, after sections of the basement floor slab were poured, steel struts varying from 40 to 60 feet in length were placed between the side walls and the edge of the floor slab, which served to support the side walls during the removal of the sloping earth berms. The side walls around the normal basement are designed to bear against the basement floor slab and are self-supporting, as cantilevers.

For the deep basement, side walls are ultimately to be supported by the structural steel and concrete floor systems of the building. It was necessary, therefore, after building these deep walls, to install a system of bracing as the general excavation in this area proceeded. The bracing is of steel, as ordinary timber cross-lot bracing offered an objectionable fire hazard. The cross-lot bracing is being stressed to predetermined amounts, using strain gages to check the stresses. Steel plates and steel wedges driven with hand hammers are being used for stressing.

During general excavation it was found that a zone of very soft supersaturated silt extended almost the entire length of the lot, varying from perhaps six to twenty feet in thickness. This stratum was so soft that in places it was impossible for men to stand on it, or to operate equipment over it. It was interesting to note, however, that

as soon as we got below this semi-liquid stratum we found gravel, and then shale, containing no water.

At the northwest corner, excavation in the wall trench was carried to about elevation 670, or nearly 80 feet below street level and 33 feet below pool level of the river. At this corner, because of an imperfect contact between the sheeting and the top of the shale, there was an inflow of water estimated at from 800 to 1000 gallons a minute, and various measures were necessary to insure satisfactory placing of the concrete footings. The last section of footings placed (about 40 feet long), at the north end of Grant Street, was placed under water, using one-yard bottom-dump buckets. This underwater job was pumped out three days after placing and was found to be practically a perfect seal except for a split joint in the sheeting which extended above the concrete; and the concrete was of excellent quality.

This is probably one of the deepest open coffer-dam trench jobs, to date. The deep basement floor and slab, and the foundation walls surrounding the entire building are designed to withstand not only earth pressures to grade but water pressures to within about 10 feet of the ground surface.

The entire interior of all basement floors and walls will be waterproofed, using the hard plaster method. Interior column footings in the normal basement section were sunk to the shale and belled out in the shale, using the so-called Gow method. It is interesting to note that after the completion of the basement walls surrounding the site, the interior piers were sunk in virtually dry ground.

DISCUSSION

C. N. Haggart, *Chairman:** I am sure that we all feel deeply grateful to Mr. Proctor for his paper. It was very interesting, very descriptive, and very inclusive. The next time some of us are looking through the cracks in the fence, maybe our minds will function a little more rapidly than they have in the past.

There are one or two that I wish to call upon for discussion, and after that the meeting will be open to anybody for discussion.

*Consulting Structural Engineer, Pittsburgh.

I would like to call upon Mr. Egge, who was of the firm of Moran & Proctor, but who, at present, is on the job here with the firm of Booth & Flinn during the construction of some foundation work.

J. J. Egge:* Would you consider it feasible, economical, and practical to employ the same open-trench method as we are now using on the post-office foundation for a building which may have to carry possibly forty tons per square foot to the rock, necessitating going down to hard shale under increasing hydrostatic pressure?

Carlton S. Proctor: I don't think it is possible to answer any general question of that kind. There could not be any hard and fast rule on that subject. I am on a committee of the American Society of Civil Engineers for the purpose of codifying miscellaneous foundation practices. I am trying to convince this committee that this is impossible; that it would lead to bad practice; and that every foundation job must be looked at as a separate entity, and carried through on that basis.

Rock that is fit for 12 tons should be impervious right down to a better rock. You progress until you finally come to a 40-ton rock. You must decide upon which is a more economical condition—a large-diameter pier at a low intensity, or a small one at a higher intensity. It is sometimes most economical and practicable to put down the pier of greater diameter to land on rock of lower intensity.

Alexis Saurbrey:† The speaker has presented a very clear and interesting paper. It was especially interesting to me because, not long ago, I had occasion to go over the plans and specifications prepared by his firm for the foundations of the new post-office building now under construction in this city. The plans were carried out in more detail than is usually the custom here, and the specifications were not only clear and complete, but very fair to the bidder. There was nothing left to the imagination; on the contrary, it was easy for the contractor to determine just what to do and how to do it.

The speaker referred to the condition of the subsoil in Philadelphia and stated that the glacier had not covered the area of that city.

*Chief Engineer, Booth & Flinn, Pittsburgh.
†Consulting Engineer, Pittsburgh.

A somewhat similar condition exists in Pittsburgh. The ice sheet did not reach Pittsburgh, but stopped some thirty miles north. The melting water brought down to this area vast masses of glacial drift, and our down-town foundations must therefore either rest upon, or penetrate, this layer of sand, clay, and gravel which lies over the solid shale. The deposits vary greatly in character, not only from one site to another, but often from one pit to another on the same site. In order to understand the precise condition here, it must be remembered that the hilltops surrounding us are remains of an old plain, into which the rivers gradually cut their present courses long before the glacial period. During the earlier stages of the glacial period, these valleys were apparently swept perfectly clean of all debris and then filled again. There is a theory to the effect that the river was choked by a dam, whether of debris or ice, near the present site of Beaver; that the waters impounded by this dam formed a more or less stagnant lake; and that this lake became the recipient of the layers which now form the soil of lower Pittsburgh. The result is the well known mixture of sand, clay and gravel in irregular streaks, pockets, and layers, interrupted here and there by reefs of boulders along the old main channels. It follows that the precise nature of the subsoil in any particular locality can be predetermined, if at all, only by extensive soil exploration. Most of the test borings that I have seen—and I have seen many in Pittsburgh—establish to perfection the level of the rock floor and the nature of the rock itself, but they fail quite often in giving a true, adequate picture of the soil between the street level and the rock floor, a point also brought out in the paper by Mr. Proctor.

Now, as regards the rock floor itself, it will be noted that the layers in this vicinity are perfectly flat and level; there is no folding of the rock in Pittsburgh, and a layer found at a certain depth in one place is likely to be found again at approximately the same level in any other locality. But we must remember that just as the main streams cut their bed into the shales, so did their tributaries, and therefore there exist, underground, many ancient gorges which have since been filled either by glacial drift or by the hand of man. The sides of these gorges are steep, so that the putting down of two or three test holes is quite inadequate; as likely as not, these holes would just miss the side of the gorge and therefore give a misleading im-

pression of the rock formation. The better plan is to put down several holes; then the record is much more likely to be correct.

From the paper under discussion, we learn that the "open" caisson is now in vogue in New York, and I am certainly glad to know that we in Pittsburgh are quite up to date in that respect, for open caissons have been used here for many years. As examples, I cite the Y. M. C. A. building at Wood Street and Third Avenue, the Keystone Club opposite, and the Koppers building. The caissons in the last-named job were put in by a contractor using the familiar Chicago well method, a method particularly adapted for the Chicago clay, but less well suited to our conditions here. On the Koppers job, it was desired to land the bottoms of the caissons in the hard blue shale, which made it necessary to penetrate the softer red and brown shales overlying the blue. The softer shales carried considerable water and it was difficult to cut off the flow of this stream, although in the end it was successfully done. Therefore, on the Gulf building, which followed shortly afterwards, a change was made to pneumatic caissons. It is true that the pneumatic method eliminates most of the trouble with the water, but it is an open question whether it is cheaper and quicker. Certainly, a lot of water can be pumped out for the cost of the pneumatic plant, not to mention the shorter hours and higher wages. It is interesting to note that the post-office, located so near both the Koppers building and the Gulf building, is founded on open caissons penetrating to the same kind of rock underlying the two earlier buildings.

In the Keystone Club, referred to above, the caissons were quite near the Monongahela River, so that the water would be a real hindrance there, if anywhere. It did bother us quite a bit, especially at the higher stages of the river. The architects, Janssen & Cocken, of this city, had alternate designs prepared for open caissons, for a continuous mat, and for a variety of piling schemes. As an aid to the bidders who desired to tender on the foundation work, a test caisson was sunk to rock under a separate contract, and the prospective bidders were invited to follow its progress down. When the bids finally came in, there was little difference in the cost of open caissons, piles, or mat. The open caissons were selected as offering the safest and most permanent return for the investment.

C. N. HAGGART, *Chairman:* We should be glad to hear from Mr. Sturges.

T. B. STURGES:* My business is the investigation and study of the subsurface strata to determine condition and bearing value, and to gain information on the type of foundation required. In making this study we take out a core of the clay, sand, limestone, shale or other material to find out its exact nature and condition.

Our company has made borings in most of the states that Mr. Proctor has mentioned, including the cities of New York, Philadelphia, Detroit, and Pittsburgh. I fully agree with him that the engineer should study this foundation problem with an open mind. Too often the building is designed before the foundation borings are made instead of having the preliminary information and then adapting the foundations to the conditions.

We made the borings for the Pittsburgh post-office that have been called in question to-night as not giving true information. In the first place, the Government is trying to economize by using the cheapest method of boring, and does not obtain the best possible information, and, due to not having the most accurate information, will probably spend many times the amount of the saving in drilling. Mr. Saurbrey has said that considerable water was encountered in the bed of sand underlying bed-rock. We made a cross-section of the boreholes and on the blue-prints I made a special note that the borings were made during the extremely dry weather and after the long drought. At that time there was very little free water in this sand, but I called attention to the fact that there would be water in wet weather. The excavation was made after heavy rains and there was water found in this sand.

No method of boring is perfect, but the engineer or architect should use the method of drilling that will give the best information possible and the engineer in charge of the work should know local conditions and interpret changes that might come with the change between wet and dry seasons, and rise and fall in nearby rivers.

*President, Pennsylvania Drilling Co., Pittsburgh.

BOARD OF DIRECTION MEETING

December 15, 1931

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor D, William Penn Hotel, Tuesday, December 15, President L. C. Edgar presiding, Messrs. Allan S. Davison, W. H. Buente, J. N. Chester, W. N. Flanagan, C. N. Haggart, C. E. Lesher, G. F. Osler, J. F. Robinson and Lauson Stone being present, Messrs. Norman Allderdice, W. L. Affelder, J. F. Laboon, F. R. Phillips, F. F. Schauer, J. A. Schuchert, G. E. Stoltz, E. C. Stone, W. B. Skinkle and A. Stucki being absent.

The minutes of the last regular meeting, held November 17, were approved without reading.

Applications from the following gentlemen, having been published to the Society pursuant to the action of the Board, were elected to membership:

MEMBERS

Downs, Edgar S. Skagen, Sverre

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Boynton, A. J. Hodgdon, T. G.
Rechtin, Eberhardt

ASSOCIATE

Archbold, George Herbert

Letters of resignation were received from the following and, after discussion, it was moved and carried that they be accepted with regret: W. N. Gallinger, F. G. Gasche, W. P. McCabe, Norton A. Newdick and D. E. Renshaw.

The report of the Secretary, showing the condition of finances at the close of business, November 30, having been audited by the Finance Committee, was approved.

The Membership Committee held one meeting to go over applications received since the last meeting of the Board and to act on any other business coming before the Committee.

Mr. Davison, Chairman of the Entertainment Committee, reported a most successful Bridge Party, held November 20, with a net profit to the Society of $8.40.

The Committee is making arrangements for the Annual Dinner, but has nothing definite to report as yet.

In accordance with Article V, Section V, of the By-Laws, the Secretary presented, for second reading, the following report of the Nominating Com-

mittee, whose names have been published to the Society in the November issue of the "Monthly News":

President ..... F. R. Phillips
Vice President .....H. N. Eavenson
Treasurer ..... A. Stucki
Directors..... { Lauson Stone, J. F. Robinson

Respectfully submitted,

G. H. Danforth, *Chairman,*
W. L. Affelder,
F. C. Biggert,
Sydney Dillon,
S. M. Kintner,
Nominating Committee.

No other nominations being received, it was finally approved and the Secretary instructed to mail ballots to the membership, January 1.

The Secretary read the following letter, dated December 9, 1931, from W. B. Spellmire:

K. F. Treschow, Secretary,
Engineers' Society of Western Pennsylvania,
Pittsburgh, Pa.

Dear Mr. Treschow:

The 1931 Convention Executive Committee of the Illuminating Engineering Society feels indebted to the Engineers' Society of Western Pennsylvania for the facilities and the assistance rendered in connection with the successful convention which has been concluded.

In recognition of all services rendered by the Engineers' Society, the Executive Committee desires to express their pleasure in the form of a contribution of $75.00. Check for this sum, payable to the Engineers' Society of Western Pennsylvania, is enclosed.

Yours very truly,

W. B. Spellmire,
Chairman, Finance and Budget Committee.

It was regularly moved and carried that the Secretary write Mr. Spellmire, expressing the appreciation of the Board for his thoughtfulness in making this contribution to the Society.

The meeting adjourned at 1:25 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION MEETING

January 19, 1932

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Crystal Room of the William Penn Hotel, Tuesday, January 19, President L. C. Edgar presiding. Messrs. A. S. Davison, W. H. Buente, C. E. Lesher, G. F. Osler, L. J. Riegler, F. R. Phillips, F. F. Schauer, W. B. Skinkle, E. C. Stone and Lauson Stone being present, Messrs. W. F. Affelder, Norman Allderdice, J. N. Chester, W. N. Flanagan, J. F. Laboon, J. F. Robinson, J. A. Schuchert, G. E. Stoltz and A. Stucki being absent.

The minutes of the last regular meeting, held December 15, were approved without reading.

Applications from the following gentlemen, having been published to the Society pursuant to the action of the Board, were elected to membership:

MEMBERS

Boynton, A. J. Hodgdon, T. G.
Rechtin, Eberhardt

ASSOCIATE

Archbold, George Herbert

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Butcher, Alfred Kerr, Albert Moore
Hart, Cecil H. Robbins, Cyrus C.

ASSOCIATE

Rhinehart, J. R.

Letters of resignation were received from the following and, after discussion, it was moved and carried that they be accepted with regret: F. T. Agthe, R. W. H. Atcherson, J. M. Brown, A. Christianson, John Davies, Eugene Dowling, Emanuel Dym, A. C. Fieldner, G. M. Gadsby, T. M. Girdler, H. O. Hill, J. K. Hallock, F. B. Hufnagel, L. F. Kuhman, V. Malevich, R. G. Mayer, H. C. Medley, C. E. Miller, P. T. Norton, G. W. Provost, E. H. Rodgers, W. B. Schiller, S. A. Stafford, T. P. Watson, B. S. Williams and E. W. Kuhl.

The following deaths are reported:

C. C. Paschedag, 2966 Voelker Avenue, Dormont, Pittsburgh, Pa.; joined Society May, 1906; died May, 1931.

H. T. Porter, Greenville, Pa.; joined Society October, 1906; died January 11, 1932.

Hugh P. Tiemann, 565 Frick Building Annex, Pittsburgh, Pa.; joined Society June, 1911; died January 4, 1932.

The report of the Secretary, showing the condition of finances at the close of business, December 31, having been audited by the Finance Committee, was approved.

The Membership Committee held one meeting to go over applications received since the last meeting of the Board and to act on any other business coming before the Committee.

In connection with the report of the Finance Committee, the Secretary stated there were unpaid bills on hand, as of December 31, amounting to $5,700. Against this amount, there were outstanding dues amounting to $8,300.

The auditor's report showed net operating income loss of $1,200. Our records show that we collected about $3,000 less in dues during the past year than collected in 1930. We also suffered a loss in advertising amounting to about $2,500, which represents about 50 per cent. of the advertising now carried in our publication.

The Secretary presented a letter from the American Engineering Council, inviting our Society to take part in the formation of a State Council of Engineers. This movement is being sponsored by the four founder societies, the American Engineering Council and the Rochester Engineering Society. The Secretary reported that a similar organization had been formed seven or eight years ago, but had not proved successful. After a general discussion, it was moved and carried that this matter be tabled.

The Secretary also presented a request from the Pittsburgh Sun-Telegraph asking our Society to endorse a suggestion of the County Commissioners to change the name of KDKA Boulevard to the Roebling Boulevard. This change was suggested as Mr. Roebling was an internationally known engineer and was born in Saxonburg. After discussion, it was moved and carried that this request be tabled.

The meeting adjourned at 1:25 P. M.

K. F. Treschow, *Secretary.*

PLASTICITY AS APPLIED TO STEEL PRODUCTS*

By A. Nadai†

I want to express my appreciation for the very kind words with which the Chairman of this meeting has introduced me to the members of the Engineers' Society of Western Pennsylvania. He spoke of my subject as new. I might be allowed to modify that statement by saying that the matter which I am trying to bring to your attention is, in several respects, not exactly new, as his kind remarks have indicated, inasmuch as it has been treated in various previous publications.

I want to say, too, that although this work has some connection with practical applications, it was not undertaken with the aim of finding out more about such conditions and circumstances as are of immediate interest to the practical engineer. We were playing around with specimens, sometimes of very strange and weak materials. For instance, we will show you some experiments with paraffin, which is not a material frequently used by engineers.

Before discussing observations on one of the most frequently used materials (mild steel) it may be in order, perhaps, to recall that in machine and structural design the engineer relies upon well developed means on which he must base his computations of the small *elastic* deformations which machine parts suffer when subjected to external loads and of the stresses acting in them. The case is, however, different if the *permanent* or plastic range of deformations of the metals is considered. The limits for the working stresses in machine parts in a number of cases may depend on the mechanical conditions under which the materials start to deform permanently and become plastic.

On the other hand, a large group of manufacturing processes using engineering materials is based on one of the fundamental mechanical properties of the pure metallic elements and some of their alloys, namely, their plastic behavior either at normal temperatures or at forging heats.

In the processes of manufacturing metals and in the forming of the ingot into new shapes, such as sheets, bars, wires, rails, or structural shapes; through cold or hot rolling; through forging or pressing

*Presented November 17, 1931. Received for publication January 20, 1932.
†Research Laboratories of the Westinghouse Electric and Mfg. Co., East Pittsburgh, Pa.

of bars; or through drawing of thin sheets into new shapes such as shells and plates, this important mechanical property of the metallic materials of construction is utilized in various ways.

An analysis of what really happens in the interior of a cold or a hot block—pressed or forged between rigid plates, where the friction acting between the ductile metal and the rigid pressure plates disturbs the uniform compressive stresses, or under the heavy loads of two rollers in a rolled sheet of metal—may help to improve these or similar processes of deforming metals into new shapes.

For this and for various other reasons set forth elsewhere* in detail, certain slight changes observable on the surface of elastic bodies have been studied carefully. It is not possible, on account of

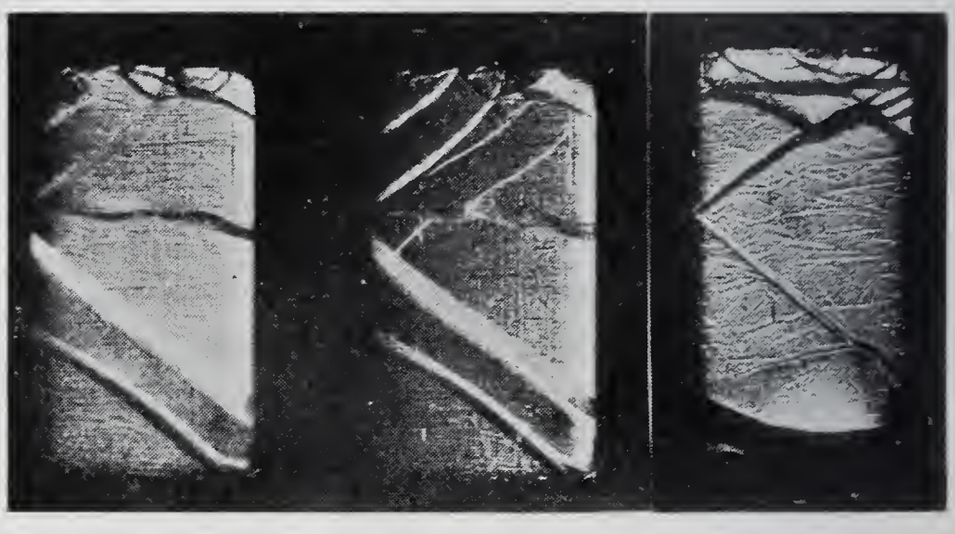

Fig. 1. Flow Figures in Mild Steel. Compression Test.

the limits of space, to reproduce here the various interesting facts which may be observed on the surface of plastically deformed specimens. Only a few illustrations are reproduced in this paper. (See Fig. 1-3 and 6.) Fig. 1 shows what would be seen on the surface of a highly polished specimen of mild steel subjected to a compressive stress just when yielding starts. Another example is shown in Fig. 2, in which the flow figures on a piece of mild steel produced by two concentrated loads can be seen. Finally, Fig. 3 is a reproduction of a photograph of the slip lines obtained by a rigid cylindrical punch. This example indicates that by pressing a cylindrical punch into a piece of mild steel it is possible to obtain a very regular system of

* "The Phenomenon of Slip in Plastic Materials," by A. Nadai. *Proceedings of the American Society for Testing Materials,* 1931, v. 31, pt. 2, p. 11.

Fig. 2. Flow Figures Produced by Two Concentrated Loads.

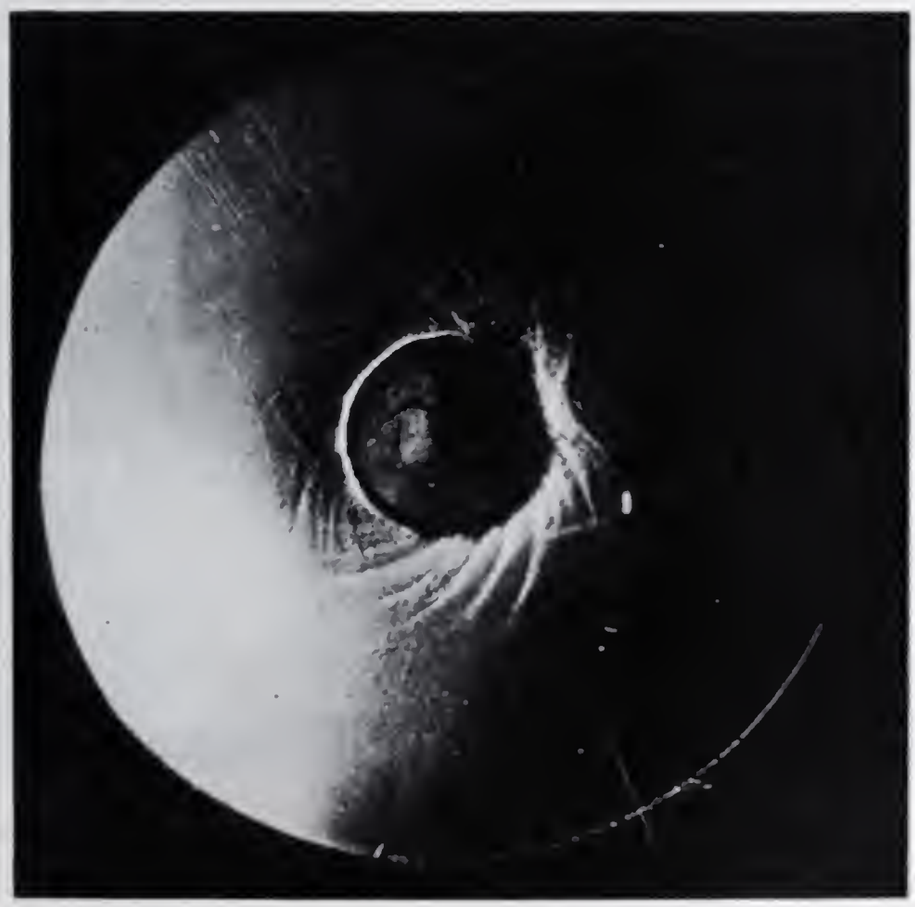

Fig. 3. Indentation of Cylindrical Punch in Mild Steel.

slip lines, which consists here in a system of curves intersecting the radii at approximately 45 degrees; that is, of logarithmic spirals.

Another case of interest is the torsion of a steel bar having a well defined yield-point. In this case, two analogies may be utilized to

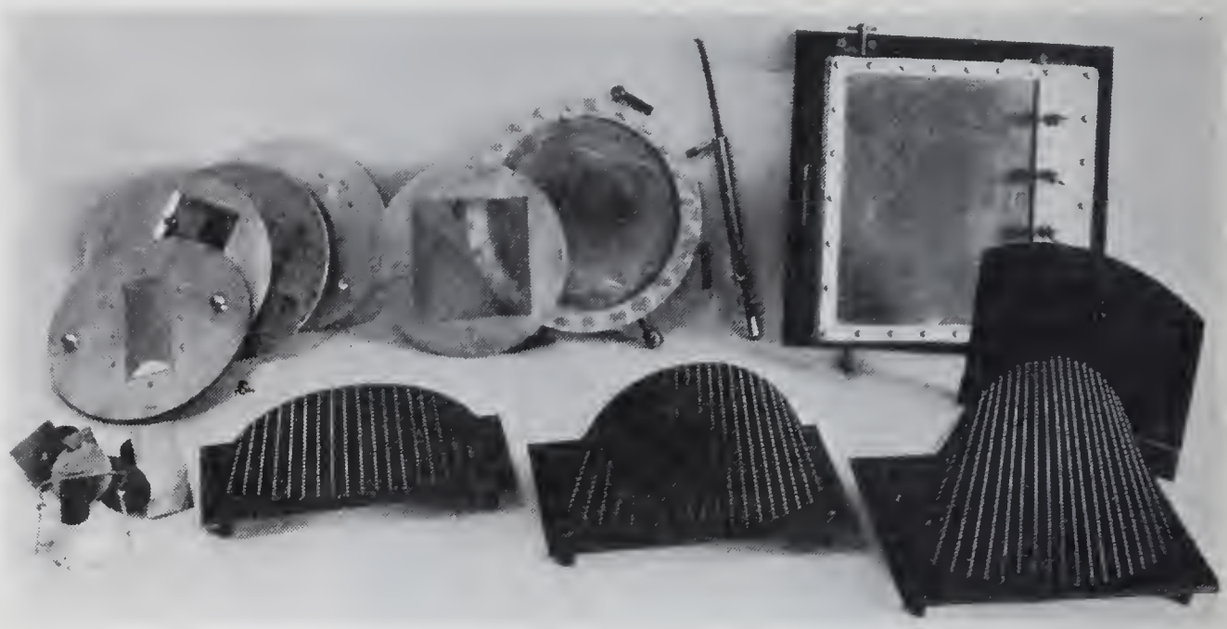

Fig. 4. Model Testing Apparatus Demonstrating Membrane Analogy of Torsion.

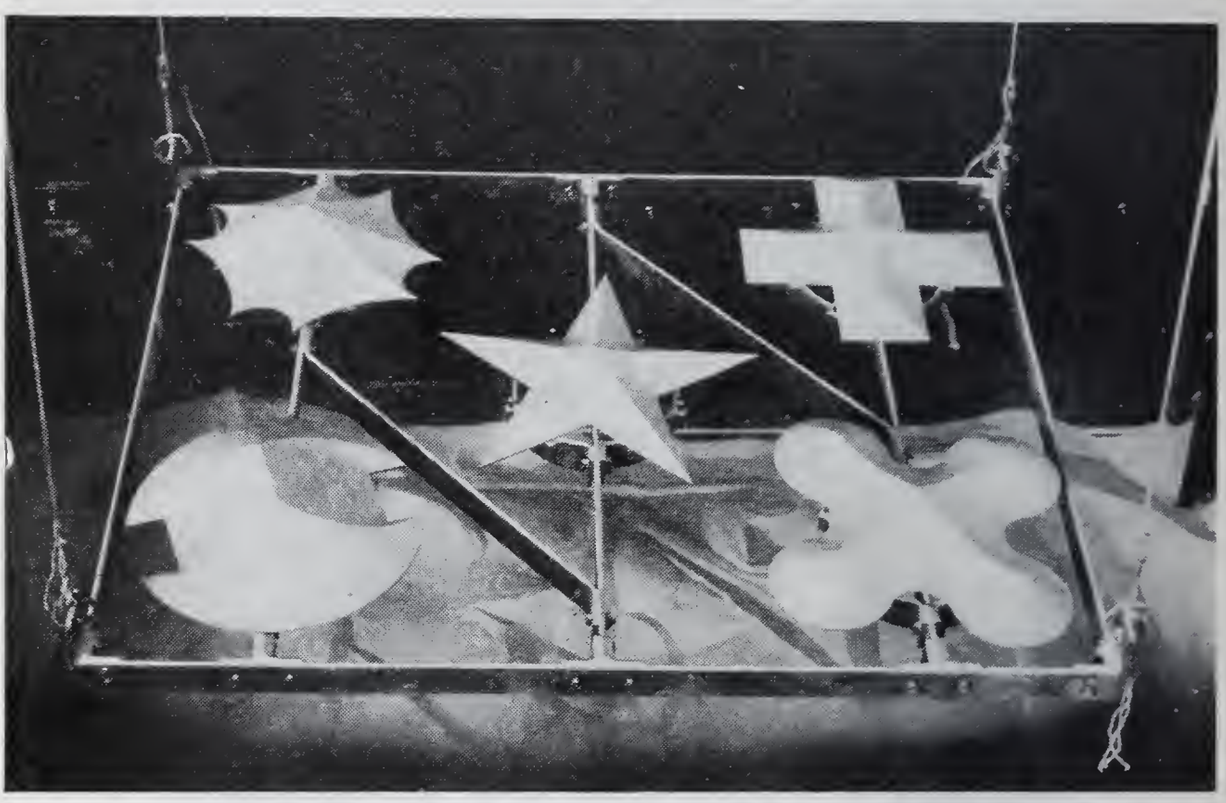

Fig. 5. Apparatus Demonstrating (by Sand Heaps) Surfaces of Constant Flow.

visualize the distributions of stress produced in straight bars of various cross-sections under torsion. For the case of the *elastic* torsion the membrane analogy of L. Prandtl* may serve to visualize the stresses. The apparatus shown in the center of Fig. 4 was used for this pur-

* "Plasticity," by A. Nádai and A. M. Wahl. 1931. McGraw, New York. p. 129-144. [The author of this paper has approved the spelling "Nadai" without the accent. Ed.]

pose. The shearing stress is proportional to the slope of a thin membrane, loaded under a lateral pressure, fastened to the edge of a hole in a plate, and of a shape made to correspond to the shape of the cross-section of the twisted bar. For the case of the *plastic* torsion the sand-heap analogy* was utilized. According to this, the shape of a sand pile, produced above a figure corresponding to the cross-section, determines the shape of the surface which was formerly represented by the membrane. The apparatus shown in Fig. 5 and the

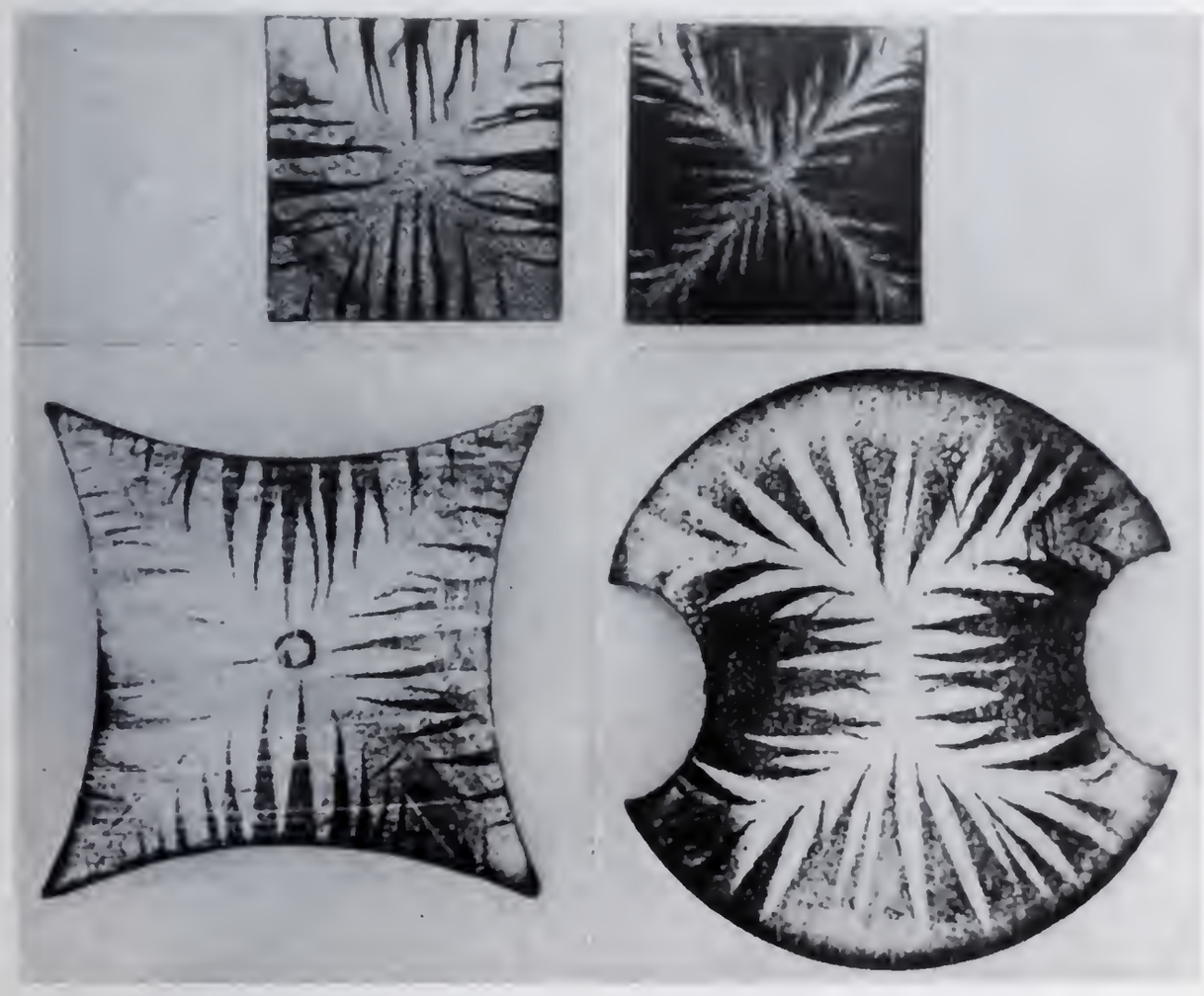

Fig. 6. Slip Lines in Twisted Steel Bars of Various Cross-Sections. Etched.

wooden models in Fig. 7 may again serve to visualize these curved surfaces, which are known to engineers and mathematicians as surfaces of constant slope. The black-wire models in Fig. 4 represent the surfaces of constant slope for elliptical cross-sections. It is remarkable that certain figures, obtained by etching of the cross-sections of twisted steel bars show a close relation to the shapes of these loose sand piles, as evidenced in Fig. 6.

**Trans. A.S.M.E.*, 1930, v. 52, pt. 1 (APM-52-17).

The structural changes produced by locally concentrated pressures in steel can also be studied by means of model tests. Parallel with these observations photo-elastic tests proved to be of practical use. These tests were made with transparent material ("bakelite" or

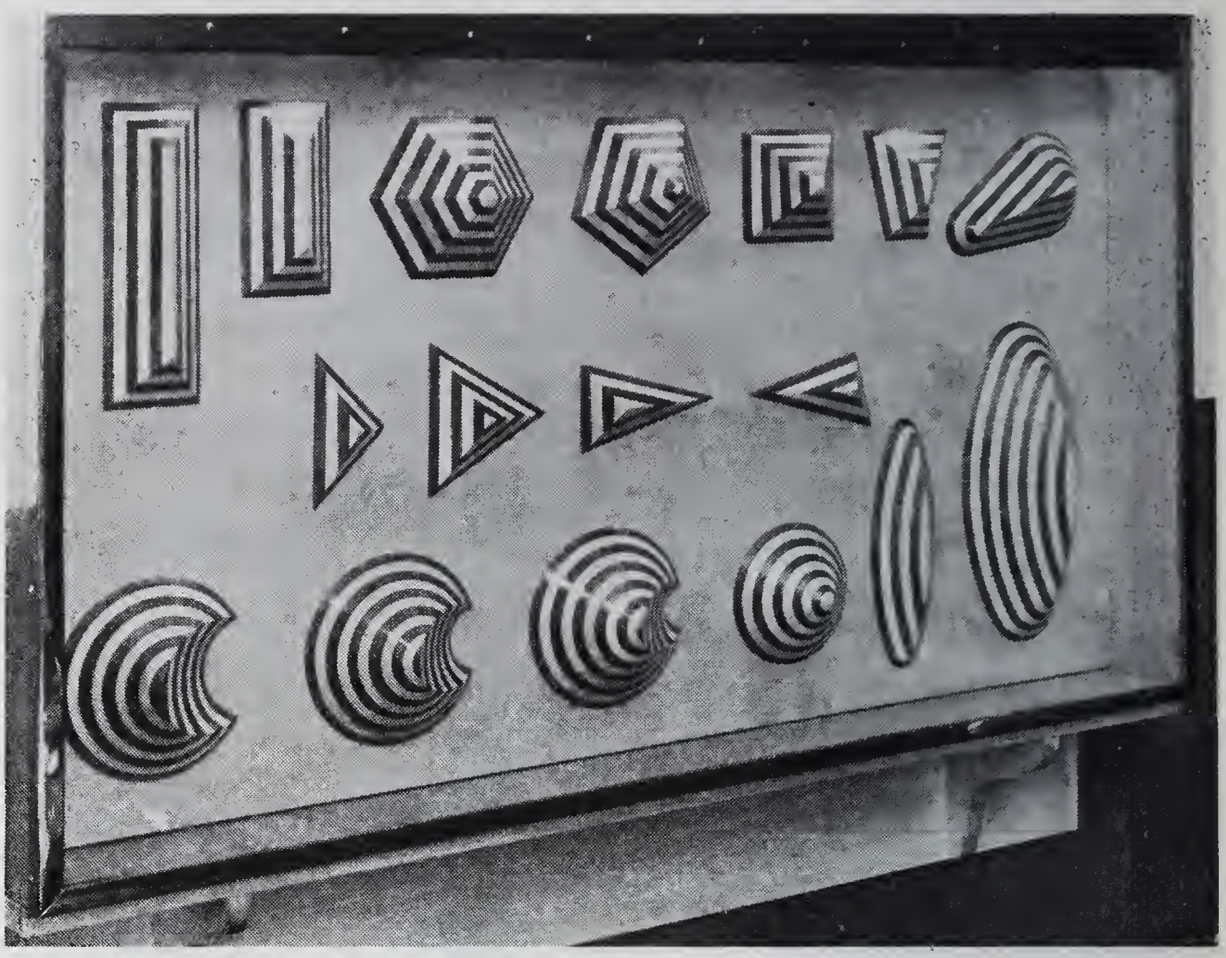

Fig. 7. Wooden Models Showing Various Examples of Surfaces of Constant Slope, Demonstrating the Distributions of Stress in Steel Bars of Various Cross-Sections Which Have Been Stressed to the Plastic Limit in Pure Torsion.

celluloid) under polarized light and under local pressure. Here again certain relations exist between the curves described as "isochromatic lines" in the photo-elastic tests (these are shown in Fig. 9 as dark bands), and the shapes of the surfaces of slip or the slip layers observed on the steel specimen. It is hoped that by a further study of these details (See also Fig. 2, 3 and 8) more will become known about the exact nature of the distributions of stress under which metals deform permanently when pressed or rolled.

Summarizing the preceding it may be said that various means may be utilized for observing how metallic pieces yield and deform under different states of stress, such as those produced by locally

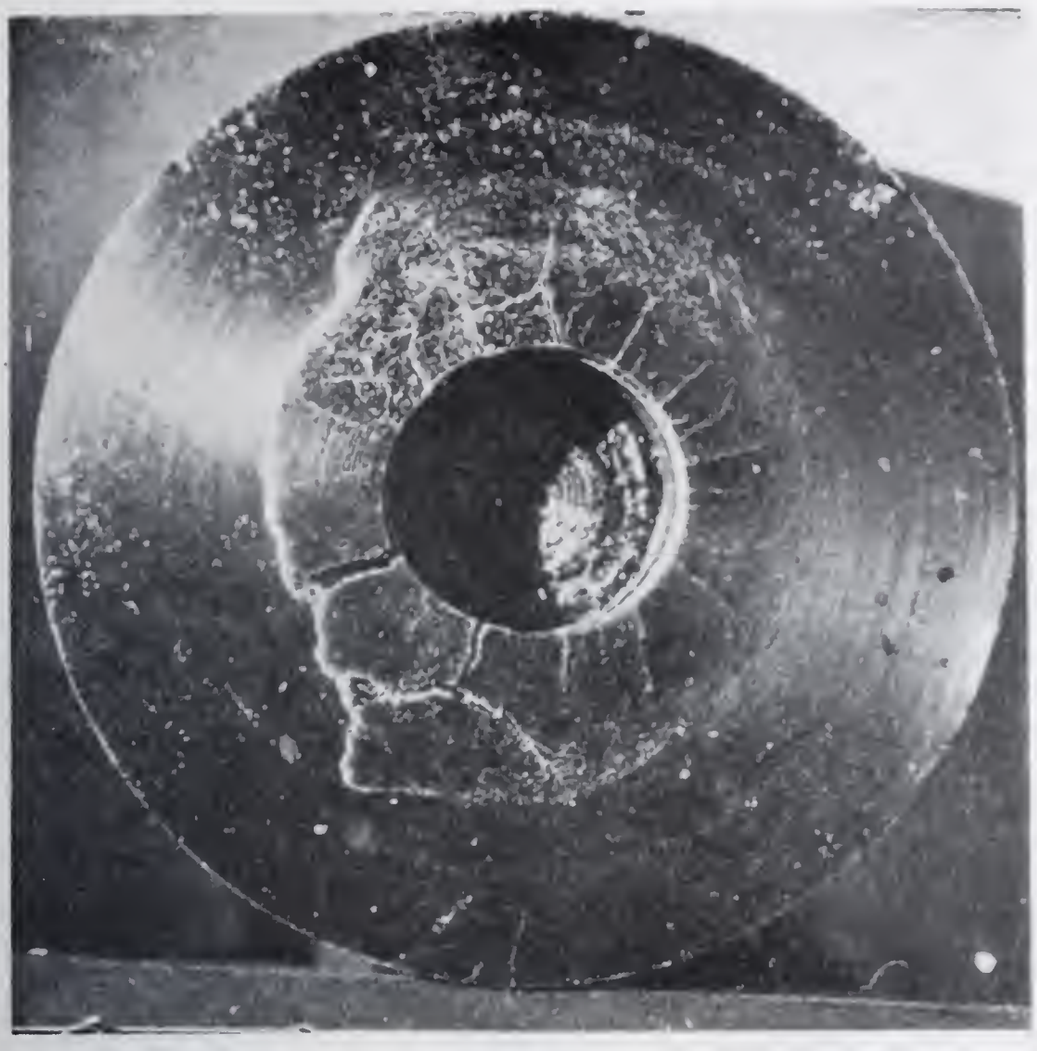

Fig. 8. Indentation of a Cylinder in Paraffin.
(Note the Radial Cracks.)

Fig. 9. Isochromatic Lines Produced by a Photo-Elastic Test. Concentrated Load.

concentrated single or double loads, through the bending or the twisting of steel bars, or through the pressing of cylinders of soft, plastic materials between rigid steel plates. Two model testing apparatuses based on analogies shown in Fig. 4 and 5 may serve to visualize the internal elastic or plastic states of stress in twisted steel bars.

DISCUSSION

W. B. Shirk, *Chairman:** Dr. Nadai was formerly a professor at the University of Goettigen, Germany, and he has been identified with quite a few investigations relating to the steel industry. He is also a personal friend of some of the German engineers whose names we all know. I am sure his talk has aroused a great deal of interest, and I am sure he invites you to ask questions which may have occurred to you during the evening. I wish everybody would participate in the discussion because that is the way we all learn.

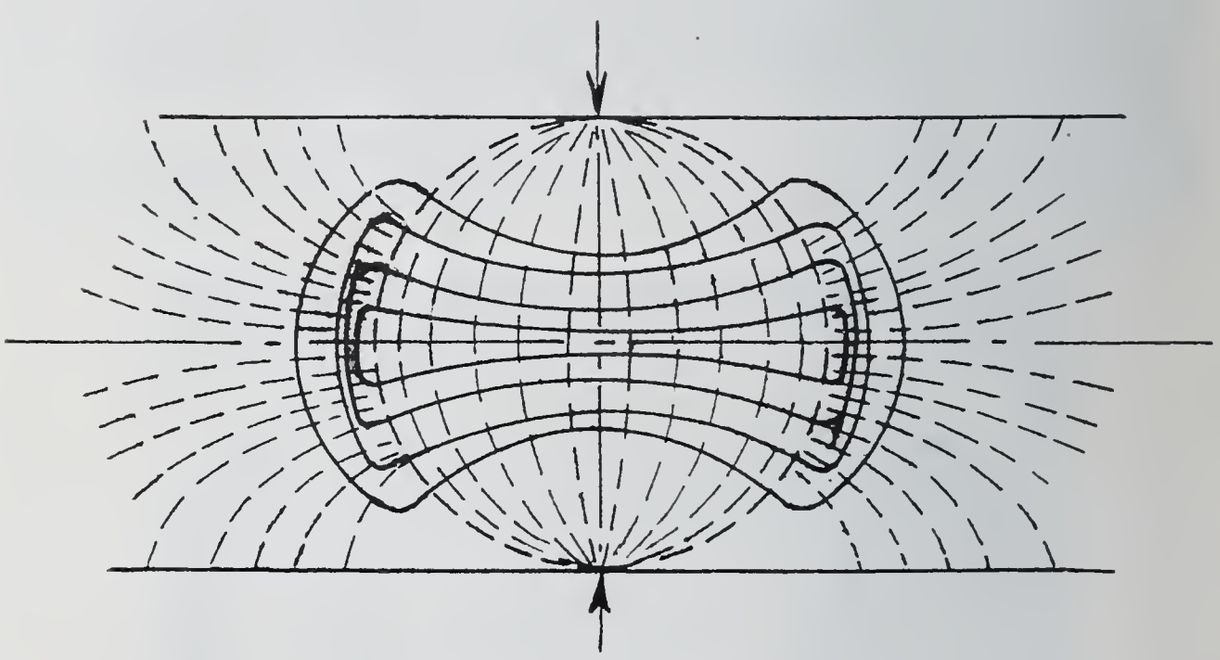

Fig. 10. Stress Trajectories.

M. M. Frocht:† One of the slides shown by the speaker contained a drawing of principal stress trajectories for a rectangular block subjected to concentrated loads as shown in Fig. 10, which is

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†Associate Professor of Mechanics, Carnegie Institute of Technology, Pittsburgh.

based on Fig. 319 in the author's book.* The family of trajectories normal to the horizontal edges of the plate seemed discontinuous, it not being clear how the two branches on opposite sides of the forces met. In the same illustration a circle could also be seen in dotted lines. Dr. Nadai did not comment on the meaning of this circle. It is, however, of some interest. In his own photo-elastic investigations the writer has observed such curves in rectangular plates and recorded them on photographs. Fig. 11 was taken with plane polarized light with the polariscope set for a zero degree isoclinic. The cross in the figure reveals this isoclinic. Fig. 12 was

Fig. 11. Rectangular Block of Glass under Stress.

taken with circularly polarized light, one effect of which is to remove the isoclinics. It follows that the remaining oval of Fig. 12 is not an isoclinic. It may mean then one of two things—either a locus of points of zero stress or of equal principal stresses. It has recently been proved† that in a square block subjected to forces as shown in Fig. 10 there are two points of zero stress on the horizontal axis of sym-

* "Plasticity," by A. Nádai and A. M. Wahl. 1931. McGraw. New York.

†See paper on "Compression of Rectangular Blocks, and the Bending of Beams by Non-Linear Distributions of Bending Forces," by J. N. Goodier, read before Annual Meeting of the A.S.M.E., New York, November 30-December 4, 1931. [Preprint.]

metry corresponding approximately to the points where the oval crosses this axis. The meaning of the rest of the curve, however, still remains unexplained.

Among the other slides shown by Dr. Nadai was one purporting to furnish a photo-elastic corroboration of the theoretical predictions for the formation of isochromatics for the case of a semi-infinite plate

Fig. 12. Square Plate of Glass with Circularly Polarized Light.

with a straight edge subjected to a uniform pressure zone. Theoretically, the isochromatics should be circles passing through the ends of the pressure zone, and Dr. Nadai seems to consider the case experimentally proved by the curves obtained by Dr. G. Mesmer and shown in Fig. 10. In the opinion of this writer, however, the photo-elastic test mentioned above provides no experimental evidence as to the validity, or lack of validity, of the theoretical conclusions. It must be remembered that the isochromatics in question were not obtained by applying a known uniform pressure and then observing the formation and shape of the isochromatics, but by filing and round-

ing the edges of an initially flat die until after numerous trials the curves in question were obtained. Such results are a bit forced. If the experiment proves anything at all it is that circular isochromatics are associated with a die and plate of definite shape. The writer fails to see, however, how this establishes the relation between the isochromatics and uniform pressure claimed by Dr. Nadai.

A slide was also shown of isochromatics under the pressure zone of a rigid flat die with sharp corners. As pictures of celluloid models go, the one referred to was a good one. It is to be regretted, however, that Dr. Mesmer, who took these photographs and who knew about "bakelite," did not use this material instead of celluloid. Had he done that he might have obtained photographs as clear as those shown in Fig. 13-15, all of which are taken with "bakelite" models

Fig. 13. Stress Concentrations Caused by Flat, Rigid Steel Die.

and monochromatic light. Note the additional sources of stress concentration in Fig. 14.

The lecture by Dr. Nadai was interesting and instructive, and the writer was particularly impressed by the good agreement be-

tween the theoretical and actual formation of the plastic regions in the various sections shown.

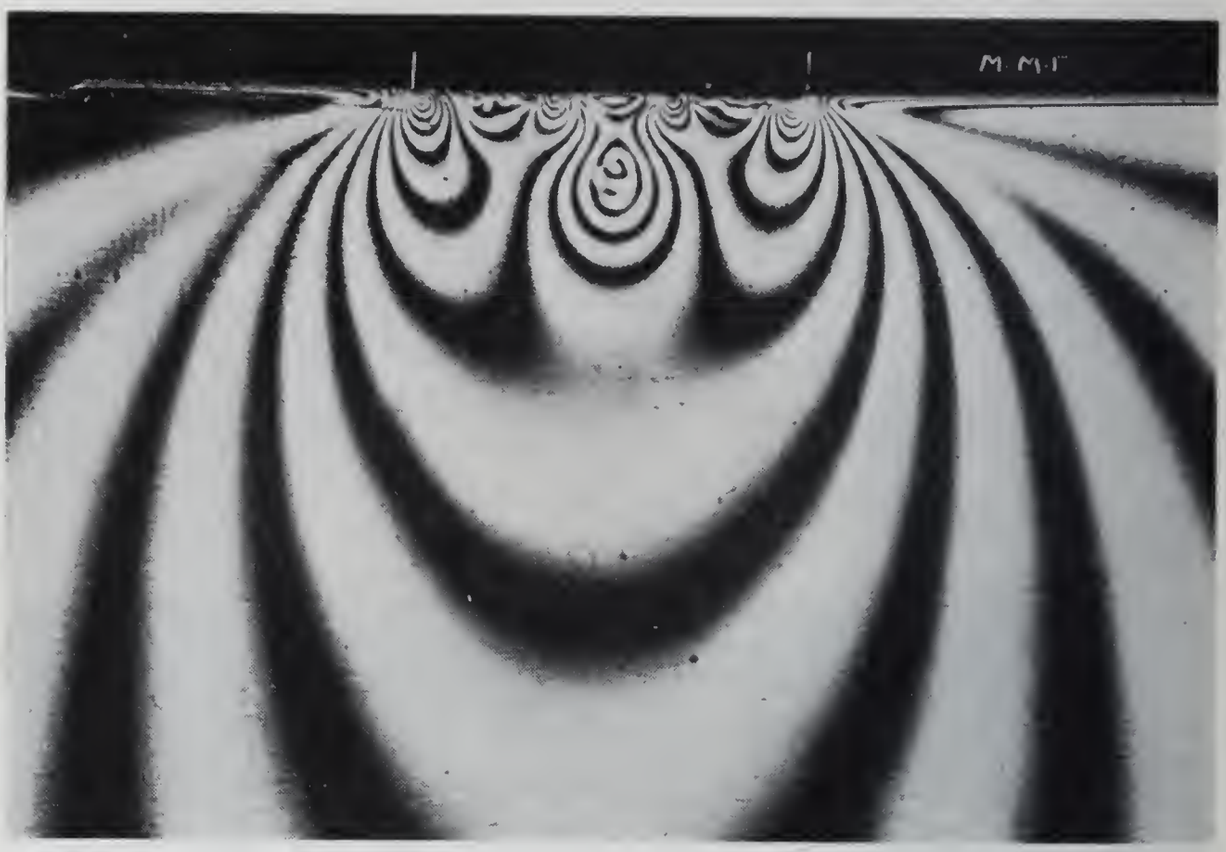

Fig. 14. Stress Concentrations Caused by Flat, Rigid Steel Die with V-Notch in Center.

C. S. Davis:* May I ask if these studies have been carried far enough to determine the effect upon the tension strength of a square bar caused by twisting it sufficiently to give it a permanent twist? As I understand it, the fibers at its center will remain in an elastic state, while those at its outer surface will have passed to the plastic state. Before twisting, a bar has a certain tensile strength. How will the tensile strength be affected by twisting sufficiently to give it a permanent twist? Would the lines of stress follow the helical curves of the fibers produced by twisting, or some other lines? Would the outer fibers which have been stressed beyond the yield-point share equally with the inner fibers in carrying the stress?

A. Nadai: Do I understand that you are interested in the behavior of straight steel bars which have been previously twisted permanently by a large amount?

*Consulting Engineer, Pittsburgh.

C. S. Davis: Perhaps I did not make my question quite clear. As a practical example, it is permissible in design to allow a unit stress of 18,000 pounds per square inch in tension on a square bar not twisted. Now if you twist this bar so as to give it a permanent spiral set, how much is it good for?

A. Nadai: I am not quite clear about the behavior of such bars when again put under stress. I may say that if a bar with a square section be twisted permanently in the cold condition it will not be

Fig. 15. Fringes Caused by a Wooden Die.

without residual stress after the torque has been removed. A bar which has been twisted permanently to a greater extent will, after the removal of the original torque, be still under comparatively heavy internal stress and there will probably be in it a system of residual stresses remaining from the former torsion and, besides this, also a second system of residual normal stresses acting in the axial direction, consisting of tensions in the outermost portions of the square sections (because of the greater length of the four edges of the bar after it has been twisted), and on account of the equilibrium conditions, which

must still hold, this system of stresses will also consist of compressions acting in the central portions of the bar. If such a steel bar is now embedded in concrete and must carry in it a tensile load, the stresses produced by this load will combine with the residual stresses and probably permanent set will be produced in the steel bar under smaller loads, as if the bar had not been twisted.

C. S. Davis: I have always opposed the use of twisted bars for reinforcing concrete.

N. Leerberg:* According to the new theory, a square shaft in torsion will have the maximum stress at the middle of the flat sides, while the corners have zero shear. Now if we take a circular shaft having a diameter equal to the sides of the square shaft, the polar moment of inertia has been decreased; but it would seem from the stress lines that the round section would be the stronger. What would be the comparison of strength?

A. Nadai: Under torsion, a bar with a square section is more rigid than the inscribed cylinder. The greatest shearing stress in the square section acts at the center of the sides of the square, while at the corners the shearing stress vanishes. This can also be easily demonstrated by using the membrane analogy of elastic torsion.

W. B. Shirk, *Chairman:* Mr. Biggert, have you any questions?

F. C. Biggert, Jr.:† I do not have any questions. I was very much interested in the whole discussion. I was particularly interested in the statement that the plastic stresses at the point just beyond the yield-point were so very similar to the elastic stresses, because in my work, while I do have some occasion to deal with plastic stresses, the main ones are the elastic stresses, because they determine the strength of parts. We have a great many cases where we would like to know more than we can calculate. It seems to me that this development gives an opportunity to apply these yield-point plastic stresses (the ones that first begin) as a means of measuring, or

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†Vice-President and Senior Engineer, United Engineering and Foundry Co., Pittsburgh.

at any rate indicating, the distribution of the elastic stresses. I do not know that Dr. Nadai has gone so far as actually to measure the elastic by the use of the plastic stresses, but I understand that he considers the latter to have a close relationship to the former.

A. Nadai: In the case of plastic torsion we may picture comparatively in a simple way the distribution of the stresses, provided the assumptions which were required to simplify the treatment are still valid. In many other cases, which are important, we do not yet know much about the distribution of stress in the plastic state. Such cases as that of a cylinder with thick walls or a tube under internal pressure, which have been stressed to the yield stress, have been treated. Another case is that of a rotating disk. In some of these cases the mathematical treatments are comparatively simple and not more complicated than in the corresponding elastic cases of equilibrium.

W. B. Shirk, *Chairman:* The hour is getting late and Dr. Nadai has some more exhibits up here. If there is no further discussion you who are interested in seeing these exhibits are invited to come forward and inspect them.

I also wish to thank Dr. Nadai on behalf of the Society for coming here to-night and presenting to us this very instructive talk.

RECENT GAS DEVELOPMENTS IN NORTHERN PENNSYLVANIA AND SOUTHERN NEW YORK*

By J. French Robinson†

The discovery of natural gas in a well near Bolivar in the town of Wirt, Allegany County, N. Y., on September 11, 1928, and in the Wayne-Tyrone field, town of Tyrone, Schuyler County, N. Y., in March, 1930, started an active leasing campaign throughout southern New York which extended on a small scale into northern Pennsylvania.

About the middle of September, 1930, the Allegany Gas Company brought in its Palmer No. 1 well, in Farmington Township, Tioga County, Pa., with an open flow of approximately fifteen million cubic feet of gas a day. This location being in wildcat territory, the gas company had not cased the well, and was not prepared to take care of a well of this size, hence it was allowed to blow open for many days. The roar of this well could be heard for many miles. The discovery of gas in the northern part of Pennsylvania attracted operators both large and small, and by the first of January, 1931, practically all the land in Tioga, Potter, Bradford, Susquehanna, Cameron, Clinton, and Lycoming counties was under lease.

On the Booth farm in Hebron Township, Potter County, Pa., the Hungiville Oil and Gas Company, on December 3, 1931, drilled in a well having an open flow of 9,000,000 cubic feet of gas a day. The well was shut down after drilling only a foot in the sand. No preparation had been made to care for a well of this size and it blew open for two weeks before the operators were able to shut it in. All of the above mentioned gas production is from the Oriskany sand.

Prior to the discoveries mentioned above, many deep wells had been drilled in southern New York state through the Oriskany sand horizon in prospecting for salt. No gas, however, was encountered in these tests. Gas and oil from the shallow sands have been produced in Potter and Tioga counties since 1884. Many years ago a well was drilled near Gaines, Tioga County, Pa., through the Oriskany sand horizon, without encountering any sand. This well was known as the

*Presented January 26, 1932. Received for publication March 1, 1932.
†Geologist and Engineer, Peoples Natural Gas Co., Pittsburgh.

"Spiritualist well." The following is quoted from "The Oil and Gas Fields of Pennsylvania," volume 1, by Dr. George H. Ashley and the author (Pennsylvania Geological Survey, Fourth Series).

"Scattered drilling in most of those [northeastern] counties has shown the presence of small amounts of gas and leads to the belief that gas in small amount may be expected in most of that section of the State. As soon as topographic mapping has covered these counties, it is hoped to make a detailed study of the wells that have found gas to determine if they are on favorable structure or not. If it shall prove that they are, little hope could be held out for larger wells than those already found; but if it shall be found that favorable structures have not yet been drilled, it is possible that much larger gas flows may be obtained."

This shows that this territory had not been condemned by geologists as a possibility for natural gas, but simply had not been thoroughly studied.

The location of the producing fields in southern New York and northern Pennsylvania is shown in Fig. 1. The Tioga County field is approximately 200 miles from Pittsburgh, 110 miles from Syracuse, N. Y., and 90 miles from Bradford, Pa.

A great handicap at the beginning of this development was the fact that no farm line maps of the territory were available. It was, therefore, necessary for the operators to make maps. However, this could not be done in time to assist in the leasing and the preliminary geological work. There are now available maps which were made by combining actual field work and using aërial photographs. The maps are to the scale of one inch to 1320 feet, and are in sheet units of 30 by 30 inches of arc, each covering 49 square miles. Approximately ten thousand square miles of prospective territory has been mapped to date. The aërial mapping in Pennsylvania was done by the Curtiss-Wright Flying Service, and in New York by the Aerotopograph Corporation of America, Inc.

The topography of northern Pennsylvania is rugged. Many streams have cut through the mountains and have formed deep gorges. The elevation above sea-level in the valleys is a thousand feet, while on some of the mountain tops the elevation exceeds 2600 feet. Prior to the discovery of these new gas fields, there had been but little geological work done in this section of Pennsylvania and New York. The geological structure of portions of Potter and Tioga counties in

Pennsylvania has been published since 1903 in the Gaines, Elkland, and Tioga quadrangles, and this represents the only detailed work published regarding this territory, except the United States Geological Survey Watkins Glen and Catatonk folios in New York.

Most of the rocks outcropping in this region and those encountered by drilling are of the Devonian Age. Because of the general south and southwest dip of the strata in this vicinity, a detailed examination of almost the entire section of Devonian rocks can be made from outcrops found between the northern boundary of Pennsylvania and the outlets of Lake Seneca and Lake Keuka in New York. Excellent exposures of the Devonian rocks can be seen along the shores of these lakes and in the adjacent ravines, and they have been studied for many years.

Northern Pennsylvania and southern New York, as well as the larger part of the entire Appalachian region was once the site of an inland sea, varying in depth and extent throughout geologic time, but always depositing sediments of varying character on its bottom. A disturbance then took place which raised the land and produced the Appalachian mountains, and at the same time caused much buckling and twisting beneath the surface.

These marine sediments are important as sources of oil and gas in nearly every known field. All of the required conditions for the accumulation of oil and gas are present in this area. These are:

1. Source beds, such as sediments from which the oil or gas is, or might be, extracted.
2. Reservoir rock, or a bed of sufficient porosity to be capable of holding oil or gas within it.
3. Favorable geologic structure for the trapping of the gas, such as a dome or a high point underground, into which the oil or gas may migrate up the bedding planes and eventually be collected.
4. A cap rock of impermeable nature so that the upper migration through the porous rock may be stopped.

The dome type of oil and gas pool is the most common structural type.

The well recognized geological horizons are the base of the Catskills (Red Beds), the Tully limestone, the Onondaga limestone, and the Oriskany sand. However, the intervals between these definite markers are somewhat irregular. The most definitely known horizon

above the Oriskany sand is the Tully limestone. The thickness of the Tully limestone varies from 80 to 90 feet and it lies approximately a thousand feet above the Oriskany sand, from which fact it is locally called "the thousand-foot lime." The interval between the Tully limestone and the Oriskany sand varies from 941 feet at the Charles Hoyt No. 1 well in Farmington Township, Tioga County, Pa. (Fig. 2, Ly-5), to 1370 feet in the F. A. Ackley No. 1 dry hole in Clymer Township, Tioga County, Pa. (Fig. 1, Ly-3). The Onondaga limestone caps the Oriskany sand and has a thickness of from 25 to 35 feet. The formation between the Tully limestone and the Onondaga limestone is black shale. In some of the wells drilled down the slopes of the anticline the Tully limestone has been mistaken for the Onondaga limestone, but after drilling a short distance into the lime the facts were soon revealed.

The Oriskany sand, which is the producing horizon in the Wayne-Tyrone, Tioga, and Hebron fields, is located at the base of the Devonian System and immediately below the Onondaga limestone. At its outcrop the Oriskany sand is very irregular and is a fairly coarse grained, somewhat loosely cemented sandstone. Small quartz pebbles are found throughout the lower part of the horizon. The principal cementing media of this sandstone are calcite and silica. Immediately below the Oriskany sand is the Helderberg limestone. The Oriskany sand outcrops at Oriskany Falls, N. Y., and has a thickness of 10 to 12 feet. It also outcrops at Yaugers Wood in Cayuga County, N. Y., where it shows a thickness of 26 feet.

From a study of well logs, the thickness varies from five to fifty feet in different localities. The horizon seems to be quite consistent, although in certain localities, as shown by a study of well records, it is apparently missing. The places where it is apparently missing include southwest Cortland County, N. Y., and southeast Tioga County, Pa., and, to date, no sand has been encountered in southern Bradford County, Pa.

The following table gives information on several scattered wells in northern Pennsylvania and southern New York. Location can be identified by reference to numbers on Fig. 1.

Herewith is a detailed log of the Lycoming Natural Gas Corporation's L. E. Shoemaker well No. 2 (See Ly-2 on Fig. 1 and 2). Correlations are based on examination of a complete set of cuttings.

Serial No.	Farm	Company	Township	County	State	Elevation	Tully lime Top	Tully lime Bottom	Oriskany sand Top	Oriskany sand Bottom	Total depth	Condition on Dec. 22, 1931
Ly-2	L. E. Shoemaker	Lycoming Natural Gas Corporation	Jackson	Tioga	Pa.	1474	2909	2991	3932	3980	7148	Dry
16	James Birtch	Hope Engineering Co.	Brookfield	Tioga	Pa.	1840	3815	3875	4864	4887	4921	Dry
Ly-19	I. B. Wheeler	Lycoming Natural Gas Corporation	Delmar	Tioga	Pa.	1822	4519	4600	5522	....	....	Drilling 5528
21	Ford	Cunningham Oil and Gas Co.	Howard	Steuben	N.Y.	1845	2740	2830	3505	3555	3640	Dry
24	J. C. Mahoney	Reserve Oil Corporation	Ledyard	Cayuga	N.Y.	830	17	35	none	none	6166	Abandoned
42	S. J. Braisted	Mosherville Oil and Gas Co.	Wells	Bradford	Pa.	1635	....	....	4729	4746	4750	Dry
68	Gilbert	Belmont Quadrangle Drilling Corporation	Wirt	Alleghany	N.Y.	2071	....	....	4630	4635	6250	4,500,000 ft.
129	Weiboldt	Cayuga Gas Co.	Elk	Tioga	Pa.	1729	5048	5125	5992	6017	6015	Dry
142	County farm	Wells Corporation	Charleston	Tioga	Pa.	1390	4175	4250	....	....	....	Fishing 5315
143	G. H. Hettick	Penn-York Co.	Towanda	Bradford	Pa.	1280	3219	3344	....	....	....	Drilling 5154
181	S. J. Booth	Hungiville Oil and Gas Co.	Hebron	Potter	Pa.	1847	....	....	4923	....	....	8,250,000 ft.
192	C. J. Olson	James Duff	Columbia	Bradford	Pa.	1856	4374	4478	5585	5645	5690	Dry
193	Charles Jerald	.....	Richmond	Tioga	Pa.	1350	....	....	....	....	....	Shut down 2880
195	Bradford Co. Agricultural School	Penn-United Co.	Wysox	Bradford	Pa.	740	3325	....	....	....	....	Shut down 5307
218	Porter	Freeman & McIntyre	Canisteo	Steuben	N.Y.	....	....	....	4106	4135	....	Salt water
226	Jud Scofield	W. W. Keefer	Richmond	Tioga	Pa.	1445	....	....	....	....	....	Shut down 3020
234	Archie Turner	Dearth, et al	Veteran	Chemung	N.Y.	....	....	....	2847	2874	3085	Dry
242	Pompelli	American-Canadian Utilities Corporation	Owego	Tioga	N.Y.	....	3260	3320	3988	4042	4130	Dry
255	C. E. Dickson	York-Penn Co.	N. Burlington	Bradford	Pa.	1646	4918	....	....	....	....	Shut down 5450
285	Lee Webb	Tri-State Gas Co.	Orange	Schuyler	N.Y.	....	....	....	....	none	2950	Dry
287	Woodard	Penn-York Co.	Harford	Cortland	N.Y.	....	1027	....	none	none	2786	Dry
302	W. J. Butters	Morris Run Coal Co.	Union	Tioga	Pa.	1410	....	....	....	....	....	Drilling 3335
324	Emporium Lumber Co.	East Penn Development Co.	E. Fork	Potter	Pa.	....	....	....	....	....	....	Drilling 800
326	C. E. Updegraf	Updegraf	Rutland	Tioga	Pa.	....	....	....	....	....	....	Drilling 275
Ly-1001	Fenner Taft	Lycoming Natural Gas Corporation	Woodhull	Steuben	N.Y.	1500	3162	....	4040	4085	4106	Dry
Ly-1003	William Hager	Benedum-Trees Co.	Catharina	Schuyler	N.Y.	....	1650	1695	none	none	5115	Dry
Ly-1004	J. C. Murphy	Paul Benedum	Elmira	Chemung	N.Y.	1336	....	....	....	....	3934	Dry
...	Wayne-Tyrone field	Lycoming Natural Gas Corporation	Tyrone	Schuyler	N.Y.	....	780	801	1705	....	....	....
...	Farmington field	Lycoming Natural Gas Corporation	Farmington	Tioga	Pa.	1849	3310	3380	4280	....	4280	....

The thickness of each horizon, the description of the material passed through, the top and the bottom of the horizon, and the divisions into geologic groups are given in this log. This represents the deepest well drilled in northern Pennsylvania, with the exception of the United Natural Gas Company's well drilled near Kane, Pa., to a depth of 7925 feet.

DETAILED LOG OF L. E. SHOEMAKER No. 2 WELL

Elevation of top of well, 1474 feet

Thickness in feet	*Description of strata*	*Depth in feet* Top	Bottom
24	Soil	0	24
	CHEMUNG GROUP		
61	Very fine grained bluish to greenish-gray sandstone with minute muscovite scales	24	85
89	Bluish to greenish-gray sandy shale	85	174
12	Very fine grained light greenish-gray sandstone, slightly calcareous	174	186
135	Greenish-gray sandy shale, slightly fossiliferous	186	321
6	Very fine grained dark grayish-brown sandstone	321	327
6	Greenish-gray sandy shale	327	333
17	Brownish-gray sandy shale	333	350
22	Greenish-gray sandy shale	350	372
6	Very fine grained greenish-gray sandstone	372	378
356	Greenish-gray sandy shale, part slightly calcareous and containing an occasional brachiopod	378	734
7	Very fine grained dark brownish-gray sandstone, somewhat calcareous	734	741
54	Interbedded dark gray shale and greenish-gray sandy shale	741	795
6	Very fine grained dark greenish-gray sandstone	795	801
96	Greenish to dark greenish-gray sandy shale with some interbedded dark gray shale	801	897
57	Dark gray shale	897	954
54	Dark greenish-gray sandy shale with some interbedded dark gray shale	954	1008
	PORTAGE GROUP (Contact between Chemung and Portage placed here tentatively)		
6	Very fine grained dark greenish-gray sandstone	1008	1014
6	Greenish-gray sandy shale	1014	1020
6	Very fine grained greenish-gray sandstone	1020	1026
48	Dark gray shale with some interbedded greenish-gray shale	1026	1074

Thickness in feet	*Description of strata*	*Depth in feet* Top	Bottom
54	Dark greenish-gray sandy shale with some interbedded dark gray shale	1074	1128
115	Dark gray shale with a little interbedded dark greenish-gray sandy shale	1128	1243
116	Dark greenish-gray sandy shale with some interbedded dark gray shale	1243	1359
14	Very dark gray, almost black, shale with some interbedded dark greenish-gray sandy shale	1359	1373
37	Dark greenish-gray sandy shale with some interbedded very dark gray shale	1373	1410
86	Dark greenish-gray sandy shale	1410	1496
97	Dark gray shale with some interbedded dark greenish-gray sandy shale	1496	1593
351	Interbedded dark gray sandy shale and dark gray shale	1593	1944
24	Grayish-black shale with some interbedded very dark gray shale	1944	1968
43	Very dark gray shale with some interbedded grayish-black shale	1968	2011
42	Very dark brownish-gray sandy shale with some interbedded very dark gray shale	2011	2053
7	Very fine grained, very dark brownish-gray sandstone, slightly calcareous	2053	2060
28	Interbedded very dark brownish-gray slightly calcareous sandy shale, and very dark gray shale	2060	2088
367	Interbedded dark gray sandy shale and dark gray shale, slightly calcareous	2088	2455
40	Very dark gray shale	2455	2495
37	Dark gray shale with some interbedded gray sandy shale	2495	2532
80	Dark brownish-gray sandy shale with some interbedded dark gray shale	2532	2612
52	Gray to dark gray shale, sandy in upper part	2612	2664
37	Gray to dark gray shale, somewhat calcareous	2664	2701
7	Very fine grained dark gray calcareous sandstone	2701	2708
20	Dark gray shale, somewhat calcareous	2708	2728
22	Gray to dark gray calcareous shale	2728	2750
	GENESEE BLACK SHALE		
159	Grayish-black shale, very slightly calcareous	2750	2909
	TULLY LIMESTONE		
50	Dark brownish-gray argillaceous limestone	2909	2959
19	Dark gray shale, somewhat calcareous	2959	2978
13	Dense very dark brownish-gray argillaceous limestone	2978	2991

Thickness in feet	*Description of strata*	*Depth in feet* Top	Bottom
	HAMILTON GROUP		
23	Dark gray shale, somewhat calcareous	2991	3014
24	Dark gray shale, slightly calcareous	3014	3038
67	Dark gray shale, very calcareous	3038	3105
51	Very dark gray shale, slightly calcareous	3105	3156
14	Black calcareous shale	3156	3170
30	Very dark gray calcareous shale	3170	3200
145	Very dark gray shale, slightly calcareous	3200	3345
37	Very dark gray calcareous shale	3345	3382
81	Very dark gray shale, very calcareous	3382	3463
	HORIZON OF STAFFORD LIMESTONE (Probably in lower part of above shale)		
34	Very dark gray calcareous shale	3463	3497
8	Grayish-black shale, somewhat calcareous	3497	3505
15	Very dark gray calcareous shale	3505	3520
72	Grayish-black shale, slightly calcareous	3520	3592
16	Very dark gray shale, slightly calcareous	3592	3608
99	Grayish-black shale, very calcareous	3608	3707
	MARCELLUS BLACK SHALE		
206	Black calcareous shale	3707	3913
	ONONDAGA LIMESTONE		
17	Very fine, dense gray to dark gray limestone	3913	3930
	ORISKANY SAND		
38	Medium grained light brownish-gray sandstone, somewhat calcareous	3930	3968
12	Medium grained dark brownish-gray calcareous sandstone	3968	3980
	HELDERBERG GROUP		
95	Very fine, crystalline, dark brownish-gray fossiliferous limestone, somewhat silicious and cherty	3980	4075
5	Very fine, crystalline, dark brownish-gray sandy limestone; also contains some dark gray chert	4075	4080
17	Very fine, crystalline, brownish-gray limestone with a little light gray chert	4080	4097
26	Very fine, dense, dark brownish-gray argillaceous magnesian limestone	4097	4123
24	Very fine, dense, dark brownish-gray argillaceous limestone	4123	4147
21	Very fine, dense, dark brownish-gray argillaceous magnesian limestone	4147	4168
10	Very fine, crystalline, light gray siliceous magnesian limestone	4168	4178

Thickness in feet	*Description of strata*	*Depth in feet* Top	Bottom
26	Very fine, crystalline, dark gray to brownish-gray argillaceous magnesian limestone	4178	4204
	TONOLOWAY LIMESTONE		
	(Probably contains horizons of Lower Manlius, Cobleskill, and Bertie)		
57	Very fine, dense, dark gray to brownish-gray argillaceous limestone with abundant crinoid stems near top	4204	4261
	SALINA GROUP (CAMILLUS FORMATION)		
28	Very fine, crystalline, light gray anhydrite	4261	4289
13	Very dark gray shale, somewhat calcareous	4289	4302
8	Very fine, crystalline, light gray anhydrite	4302	4310
18	Very dark gray shale, slightly calcareous	4310	4328
7	Very fine, crystalline, light gray anhydrite	4328	4335
6	Very fine, dense, brownish-gray argillaceous magnesian limestone	4335	4341
53	Very dark gray shale, in part somewhat calcareous	4341	4394
5	Very fine, crystalline, brownish-gray anhydrite, somewhat calcareous	4394	4399
25	Brownish-gray calcareous shale containing some anhydrite	4399	4424
	SYRACUSE SALT		
36	Coarse, crystalline, grayish-white salt with a little interbedded light gray shale	4424	4460
26	Light gray to brownish-gray shale, slightly calcareous	4460	4486
41	Coarse, crystalline, grayish-white salt with a little interbedded light gray shale	4486	4527
6	Light gray shale, slightly calcareous	4527	4533
209	Coarse, crystalline, grayish-white salt with a little interbedded light gray shale	4533	4742
6	Light brownish-gray shale, somewhat calcareous	4742	4748
20	Coarse, crystalline, grayish-white salt with a little interbedded light gray shale	4748	4768
22	Gray shale, slightly calcareous	4768	4790
127	Coarse, crystalline, grayish-white salt with a little interbedded light gray shale, partly calcareous	4790	4917
75	Light gray shale, somewhat calcareous, with some interbedded salt	4917	4992
19	Coarse, crystalline, grayish-white salt with some interbedded light gray shale, somewhat calcareous	4992	5011
14	Light gray shale, somewhat calcareous	5011	5025

Thickness in feet	*Description of strata*	*Depth in feet* Top	Bottom
55	Coarse, crystalline, grayish-white salt with some interbedded light gray shale, somewhat calcareous	5025	5080
12	Gray calcareous shale	5080	5092
6	Coarse, crystalline, grayish-white salt	5092	5098
6	Gray shale, somewhat calcareous	5098	5104
16	Coarse, crystalline, grayish-white salt with some interbedded light gray shale, somewhat calcareous	5104	5120
6	Light gray shale, slightly calcareous	5120	5126
6	Coarse, crystalline, grayish-white salt	5126	5132
26	Light gray to brownish-gray shale, somewhat calcareous	5132	5158
7	Coarse, crystalline, grayish-white salt	5158	5165
184	Gray to dark gray calcareous shale with some interbedded anhydrite in upper part and salt in lower part	5165	5349
110	Coarse, crystalline, grayish-white salt with a little interbedded gray shale, somewhat calcareous	5349	5459
6	Gray, very calcareous shale containing a little anhydrite	5459	5465
62	Very fine, dense, dark brownish-gray argillaceous magnesian limestone containing a little anhydrite	5465	5527
25	Coarse, crystalline, grayish-white salt	5527	5552
7	Very fine, dense, dark brownish-gray argillaceous magnesian limestone	5552	5559
18	Very dark gray calcareous shale	5559	5577
24	Very fine, dense, dark brownish-gray argillaceous magnesian limestone containing a little anhydrite	5577	5601
44	Coarse, crystalline, grayish-white salt with a little interbedded brownish to dark brownish-gray shale, somewhat calcareous	5601	5645
13	Very fine, light gray argillaceous anhydrite, calcareous	5645	5658
32	Light gray to brownish-gray shale, somewhat calcareous, with some interbedded anhydrite	5658	5690
5	Very fine, light brownish-gray anhydrite, somewhat calcareous	5690	5695
87	Light gray to gray shale, somewhat calcareous, containing some anhydrite in upper part	5695	5782
69	Very fine, crystalline, dark brownish-gray argillaceous magnesian limestone	5782	5851
12	Light brownish-gray calcareous shale containing some anhydrite	5851	5863

Thickness in feet	*Description of strata*	*Depth in feet* Top	Bottom
6	Very fine, dense, light to dark brownish-gray argillaceous limestone	5863	5869
172	Light to dark gray calcareous shale containing a little anhydrite	5869	6041
14	Coarse, crystalline, grayish-white salt with some interbedded dark gray shale, somewhat calcareous	6041	6055
13	Gray to dark gray shale, somewhat calcareous	6055	6068
19	Very fine, dense, dark brownish-gray argillaceous magnesian limestone	6068	6087
33	Very fine, dense, very dark brownish-gray argillaceous limestone	6087	6120
14	Coarse, crystalline, grayish-white salt with some interbedded gray shale, somewhat calcareous	6120	6134
13	Brownish-gray shale, very calcareous	6134	6147
19	Coarse, crystalline, grayish-white salt with a little interbedded dark gray shale, somewhat calcareous	6147	6166
24	Very fine, dense, very dark brownish-gray argillaceous magnesian limestone	6166	6190
6	Very fine, dense, very dark brownish-gray argillaceous dolomite	6190	6196
37	Gray calcareous shale	6196	6233
94	Coarse, crystalline, grayish-white salt	6233	6327
8	Very fine, dense, very dark brownish-gray argillaceous limestone	6327	6335
7	Light gray shale, very calcareous	6335	6342
7	Coarse, crystalline, grayish-white salt	6342	6349
9	Gray shale, somewhat calcareous	6349	6358
60	Coarse, crystalline, grayish-white salt with a little interbedded gray shale, somewhat calcareous	6358	6418
29	Dark brownish-gray shale, very calcareous	6418	6447
6	Coarse, crystalline, grayish-white salt with considerable interbedded dark gray shale, somewhat calcareous	6447	6453
36	Dark brownish-gray shale, very calcareous	6453	6489
19	Coarse, crystalline, grayish-white salt with a little interbedded dark gray shale, somewhat calcareous	6489	6508
11	Very fine, dense, very dark brownish-gray argillaceous limestone	6508	6519
11	Gray to brownish-gray calcareous shale	6519	6530
	VERNON SHALE (BLOOMSBURG)		
114	Light greenish-gray shale, somewhat calcareous	6530	6644
44	Light greenish-gray shale, slightly calcareous	6644	6688
44	Light greenish-gray shale	6688	6732

Thickness in feet	*Description of strata*	*Depth in feet* Top	Bottom
43	Light greenish-gray shale, slightly calcareous	6732	6775
30	Dark gray shale, somewhat calcareous, containing a little anhydrite	6775	6805
76	Light greenish-gray shale, slightly calcareous	6805	6881
144	Interbedded light greenish-gray and dark gray shale, somewhat calcareous	6881	7025
9	Light greenish-gray shale, somewhat calcareous, with some interbedded brownish-red shale, also somewhat calcareous	7025	7034
91	Purplish-red shale, somewhat calcareous	7034	7125
23	Purplish-red shale, slightly calcareous	7125	7148

The above correlation is based upon the examination of a complete set of cuttings by Dr. Charles R. Fettke, of Pittsburgh.

The positions of the axes of the more important anticlines and synclines in northern Pennsylvania and southern New York are shown in Fig. 1. It will be noted that the major folds extend in a northeasterly direction to a point of intersection with a north-and-south line through Lake Seneca. From the intersection with this line, the course of the folds becomes nearly east and west. A detailed structure map of the Sabinsville anticline in the vicinity of Farmington Township is shown in Fig. 2. Every well within the limits of this sheet is shown thereon with a corresponding serial number. The elevation of the top of the Oriskany sand is shown as so many feet below sea-level. Note the relation of production to the crest of the anticline.

All of the producing wells from the Oriskany sand horizon have been located on structure. The production in the Wayne-Tyrone field in New York, and in the Tioga County field and the Hebron field in Pennsylvania, forms quite a contrast with production in other portions of the eastern field. In southwestern Pennsylvania and in West Virginia some 48 gas-producing horizons are encountered, and production is obtained on the crest of the anticline, along the slopes, and even in the synclines; while in the above mentioned fields no production has as yet been found except in wells located near the crests of the anticlines. All production, to date, in northern Pennsylvania has been obtained from the Sabinsville anticline in Tioga County, and the Hebron anticline in Potter County, while the pro-

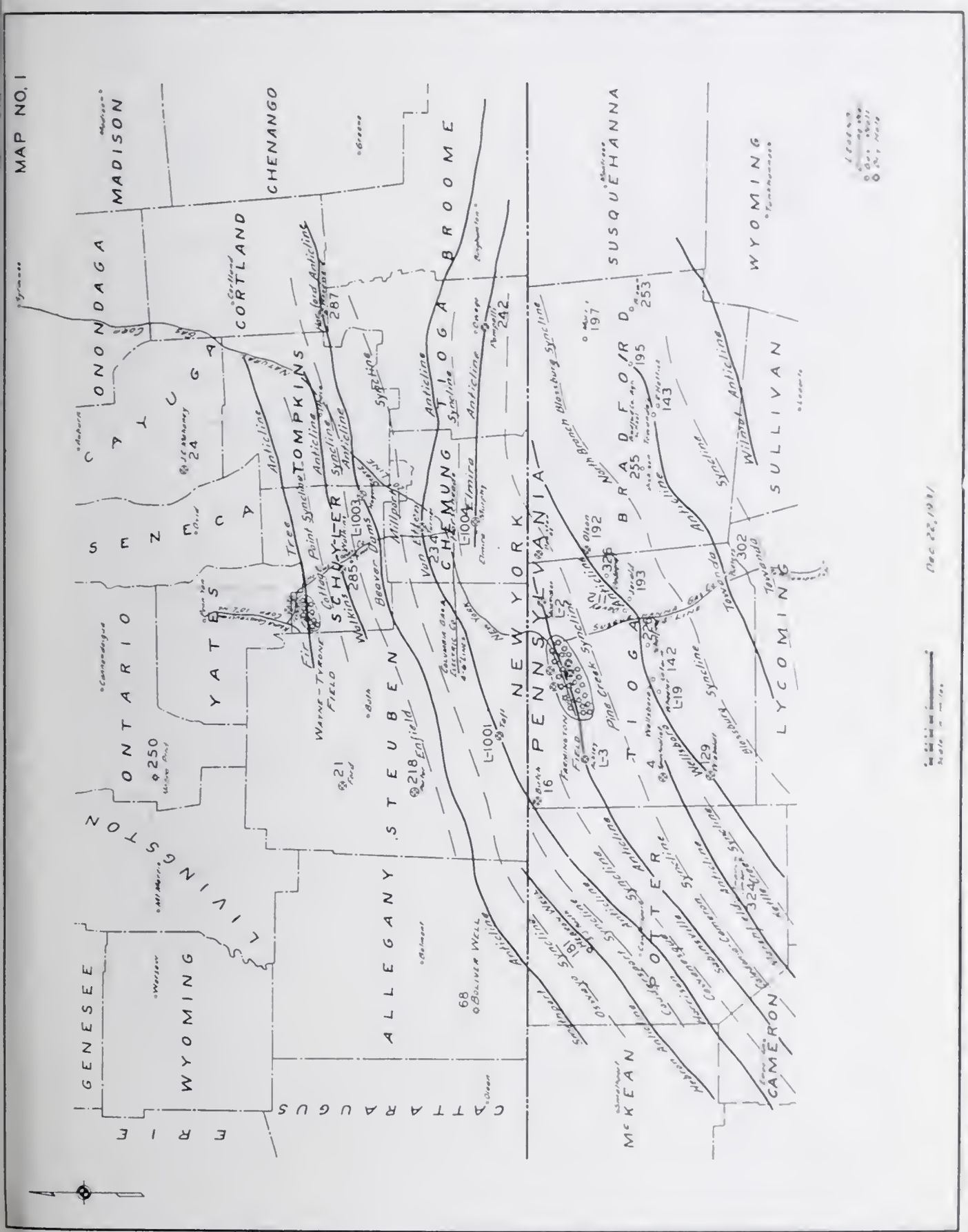

Fig. 1. Wayne-Tyrone Field in Schuyler County, N. Y., Farmington Field in Tioga County, Pa., and Hebron Field in Potter County, Pa., Showing the More Prominent Structural Axes.

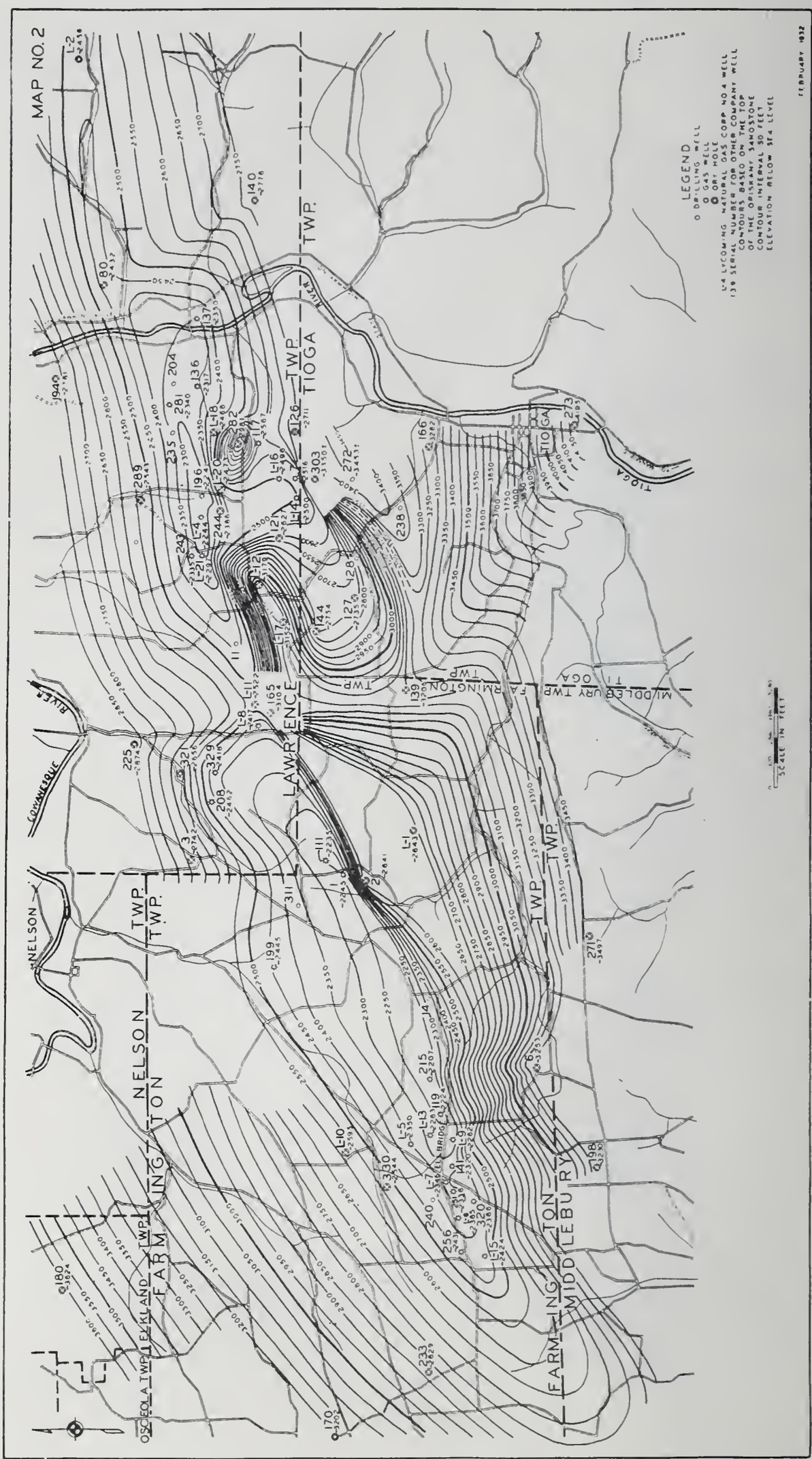

Fig. 2. Sabinsville Anticline, Tioga County, Pa.

duction in New York is on the Fir Tree anticline. Unfortunately, not all wells which are located on the anticlines have proved to be producing wells. This is accounted for in two ways, namely, faulting and sand conditions.

Many faults have been encountered in the Tioga County development (Fig. 2), some large and some small. The largest of these is the one starting southwest of the discovery well, passing between the Palmer No. 1 well (Fig. 2, No. 1) and the Kemp dry hole (Fig. 2, No. 2), extending northeasterly through the A. C. Smith dry hole (Fig. 2, No. 165) and the Farr No. 2 dry hole (Fig. 2, Ly-11), swinging in an easterly direction, passing through the dry hole on the Boom farm (Fig. 2, No. 244) and the dry hole on the Herrington farm (Fig. 2, Ly-20), then extending eastward between the dry hole on the Midaugh farm (Fig. 2, No. 282) and the Tremaine well (Fig. 2, No. 137). Several minor faults are detected running nearly at right angles to this major fault. Due to this disturbance, many dry holes were drilled on what seemed to be perfect locations. In the early stages of development it was doubtful whether any faulting existed. After several wells had been drilled and faults were encountered, a more detailed study was begun. Quite a large amount of geophysical work (by seismograph) has been done, and it is believed that this type of work will do much to eliminate dry holes by pointing out positions of the faults, and determining more accurately the crests of the anticlines.

The drilling in this field is being done by the standard cable tool method, using an 80-foot derrick. The cost of the average well in Pennsylvania will be in the vicinity of $17,500; the maximum cost with which the writer is familiar is $50,000. The cost of an average well in the Wayne-Tyrone field, New York, will be in the vicinity of $6000.

The common method of casing a well is a joint or two of 13-inch casing used for a conductor; 200 to 300 feet of 10-inch casing; 750 to 1000 feet of 8¼-inch casing; and approximately 4000 feet of 6⅝-inch or seven-inch (outside diameter) casing. The weight of this pipe varies from 24 to 30½ pounds per foot. Some operators are casing their wells with 5 3/16-inch casing. Within the proved areas, the long string of pipe is "cemented in." Some operators lower the string of pipe into 75 to 100 feet of neat cement which has been

placed in the bottom of hole by means of a dump bailer. A heavy shoe is used on the bottom of the pipe. As the string of pipe is lowered into the hole, the cement is crowded around the pipe on the outside. By other operators, the cement is forced on the outside of the pipe by means of water pressure, using several hundred feet of cement. The average depth drilled in northern Pennsylvania will vary from 4000 to 4500 feet. The deepest well drilled in the Tioga County field, to date, is the Shoemaker dry hole, referred to herein (Fig. 1 and 2, Ly-2), which is 7148 feet deep. It requires from sixty to ninety days to complete a well in this territory.

The producing pools are outlined in Fig. 1.

Wells have varied from a few hundred thousand cubic feet of gas to nearly one hundred million cubic feet of gas a day, open flow. Two of the largest wells east of the Mississippi River have been completed in this field. One was the Penn-United Company's Meeker No. 1 well (Fig. 2, No. 7), and the other the Lycoming Natural Gas Corporation's M. P. Close well (Fig. 2, Ly-14). Each well had an open flow of between 75,000,000 and 100,000,000 cubic feet of gas a day.

The rock pressure of the Tioga County field in Pennsylvania varies from 1650 to 1740 pounds. The average size of a producing well would be 20,000,000 cubic feet of gas a day. Only one deep well has been completed in Potter County, Pa., to date, it being the one referred to in the beginning of this paper, which was drilled by the Hungiville Oil and Gas Company to a depth of 4923 feet (Fig. 1, No. 181). The rock pressure of this well is 2125 pounds.

The average open flow of the wells in the Wayne-Tyrone field is about 4,000,000 cubic feet of gas a day. The average depth is less than 2000 feet, and the rock pressure is in the neighborhood of 750 pounds.

The size of the wells in all the fields depends upon the character of the sand, which factor depends upon the porosity and the permeability.

It has been suggested by Dr. Ashley and Dr. Fettke that the production from the Tioga County field is crevice production. The writer does not confirm this, but is of the opinion that nearly all the production is obtained from the pore spaces of the sandstone, the same as with other production in Pennsylvania. The fact that our smaller

wells have been obtained from the sand in which our porosity has been the lowest, and that we continue to get pay for an interval of 10 to 12 feet in the sand, indicates that this could not be from crevices. It is possible that small fractured areas play a part with the porosity in the producing zones.

In the Wayne-Tyrone field, approximately one hundred wells have been drilled within the proved area itself. Very few of these have been dry holes, though dry holes are encountered around the edges and occasionally within the proved area. The western end of the Wayne-Tyrone field is a town-lot drilling proposition. In the village of Wayne many wells are being drilled on lots, the area of which is less than half an acre. It is evident that these wells will have a very short life, and many investors will never receive the amount of their investment.

Several dry holes have been completed in purely wildcat territory in New York. Some of these were well located geologically, while others were not so well located.

In the Tioga gas field, 25 producing wells have been completed, with a total open flow of 500,000,000 cubic feet of gas daily. Within the so-believed proved area of the Tioga field eight dry holes have been completed. In northern Pennsylvania, 16 additional dry holes have been completed which were well located on structure, and were being drilled as purely wildcat wells. It is of interest to note that out of the 36 dry holes completed in northern Pennsylvania, eight were located off structure and had no chance for production.

It is the writer's belief that by the use of geophysical prospecting (by seismograph) and by more detailed study of sand conditions, this percentage of dry holes can be materially decreased within a proved area. It will be necessary to continue drilling a large number of dry holes in order to discover new fields.

There are many promising looking areas, well located on structure, that have not as yet been tested, and it is the writer's belief that several of these locations will in the future prove to be commercial gas fields. Very little gas has been marketed from this area, hence no figures are available regarding reserves. Taking, however, the porosity, the thickness of pay, and the rock pressures of the wells into consideration, it can be seen that the proved area should yield at least 10,000,000 cubic feet of gas to the acre in the Pennsylvania

fields, and about 3,000,000 cubic feet to the acre in the Wayne-Tyrone field.

The heating value of the gas in this region varies from 1015 to 1058 B.t.u. Methane is the principal constituent, varying from 81 to 99 per cent.

In order that gas wells or gas fields may have any value it is necessary to have markets. The markets usually are located some distance from the producing fields, and it is therefore necessary to transport the gas from the field to the market. At the present time one 14-inch welded line has been completed from the Tioga field in Pennsylvania to Williamsport, Pa. This line was constructed by the Susquehanna Gas Company, for a distance of approximately fifty miles.

A 20-inch line is now under construction from the Tioga County, Pa., field to Syracuse, N. Y., a distance of 110 miles. This line is being constructed by the New York State Natural Gas Corporation. It is to be dresser coupled, being constructed out of 20-foot and 40-foot lengths of pipe. The 20-foot lengths of pipe weigh 1400 pounds and the 40-foot lengths weigh 2800 pounds. This line will transport approximately 90,000,000 cubic feet of gas daily with a field pressure of 400 pounds and a delivery pressure of 100 pounds. Due to the rock pressure of 1650 pounds in the field, compressing stations will be unnecessary for the present. Three rivers were crossed with this line, and in order to safeguard against a break in service five 10-inch lines were laid across each river and connected to the 20-inch line by means of a header on each shore. This 20-inch pipe-line is being buried 34 inches beneath the surface of the ground. The average cost of a mile of 20-inch line through this territory will be approximately $25,000. It is expected that the 20-inch line to Syracuse, N. Y., will be completed and ready to deliver gas by the first of March, 1932.

The gas will be distributed in small towns, villages, and cities for both domestic and industrial purposes. In many cases the natural gas will be mixed with artificial gas, which is now being supplied and will be delivered to the consumer in this way.

DISCUSSION

S. W. MEALS:* How much gas have you taken from this field?

J. FRENCH ROBINSON: Up to the present time very little gas has been marketed from the Tioga field. Most of it has been sold in Corning, N. Y., Elmira, N. Y., and other local areas. A little is now being piped to Williamsport, Pa. For the past two years the Wayne-Dundee field has been producing 3,000,000 to 5,000,000 cubic feet a day.

L. E. YOUNG:† How does the faulting affect the possibilities for gas over a large area?

J. FRENCH ROBINSON: The faulting in this field is something new to us in the Appalachian field. We have had very little disturbance of this nature in our oil- and gas-field. The faulting in this particular field is much more than was at first anticipated. The major fault has been traced in the Tioga County field for about 2½ miles, and other faults at right angles to the major fault are evidenced. Just to what extent these faults will affect production has not been determined. Apparently good locations in the Tioga County field proved to be worthless on account of the disturbance in the fault zone.

K. C. HEALD:‡ I wish to comment on the faulting that appears to be present in the Tioga field. I have not been on the ground, but judging from the map shown by Mr. Robinson there is present a major fault at least eight or nine miles long. Judging from the map there should also be another fault to the south of this large one with a "graben" or down-dropped block between the two. The geologic structure looks quite complicated and I fear there will be a number of unfortunate situations and that some of the people who now think their acreage will cover part of the field will find themselves out of it. On the other hand, this should be somewhat compensated for by surprises of the opposite nature whereby some of the people who fear their acreage is outside of the producing area will find that they actually control a part of the field.

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†Vice-President, Pittsburgh Coal Co., Pittsburgh.
‡Staff Geologist, Gulf Refining Companies, Pittsburgh.

The geologic story will not be complete until these faults are definitely located and are explained. As Mr. Robinson said, structure of this type, with folds faulted on the side from which the thrust that produced the folding came, is practically new to students of Appalachian structure and at present we have no good explanation for the origin of these faults and for their possible significance in connection with the structural conditions that are likely to exist elsewhere in the Tioga area. As I understand it, the faults do not show up on the surface the way they are shown on the map. If that is true in the Tioga field it should also be true elsewhere in the general district, and this should be borne in mind in connection with some of the other structures that look promising. Tests that resulted in dry holes, in spite of the fact that they seemed favorably located insofar as our present geological knowledge would indicate, are perhaps not at all well located with respect to subsurface conditions. It is hoped that geophysical work with the reflection seismograph will help to clarify the conditions, but I would warn against too much optimism that all the difficulties can be recognized by such methods. The reflection seismograph seems to be outstandingly the best method now available for working out the relationships between surface and subsurface structure, but our knowledge is still limited and one can go wrong on geophysics even in areas where the geology is much less complex than it is in the Tioga territory.

Another point that interested me was Mr. Robinson's statement that there is some difference of opinion as to whether the gas comes from fractures in the tightly cemented bed or from true porosity in the Oriskany sand. I note that the rock pressures recorded in the gas-wells throughout this territory are in every case very nearly equivalent to the hydrostatic head, and I believe this indicates continuity of porosity. This, in turn, probably rules out fissures as the only openings containing the gas, since I should not expect fissuring to be so continuous and so interconnected as to permit the close adjustment of the gas pressures to the hydrostatic head that is indicated by the records in the area.

Another point of interest is Mr. Robinson's statement that the Oriskany sand is absolutely missing in some of the wildcat wells that have been drilled in the territory. This seems quite significant and may mean that some of the tests that have been drilled are not as condemnatory of the possibilities of the territory as they seemed

when first completed and abandoned. If the sand is missing on the top of the structure this means either erosion in post-Oriskany time or no deposition. In either case there should be a chance for production on the flanks of this structure since the structural conditions should, on a small scale, be analogous to those in that part of the Oklahoma City pool which is productive from the Wilcox sand that is absent over the top of the structure but richly productive on the flanks.

S. W. MEALS: Was water found in the Oriskany sand in all dry holes drilled in the Tioga field?

J. FRENCH ROBINSON: I can tell you what happened, but I can not tell you why it happened. Some of the wells down the slope encountered water; other wells considerably deeper on the structure in the same area were free from water. The deepest well, geologically, in the field was perfectly dry in about 50 feet of sand. Both the well to the north and the well to the south had holes full of water. There have been many wells in the field which encountered no water whatever.

That might be explained. The seismograph has given us a record similar to several waves instead of one axis. The Meeker well No. 2 went down into a dip; the next well, about 2000 feet away, came back up. There seem to be three separate rolls in the structure itself. That may help explain the water situation.

C. A. BONINE:* Mr. Robinson's paper forms a very valuable addition to our fund of knowledge on the occurrence of gas in the Oriskany sand in the northern tier of counties in Pennsylvania.

The author's conclusions that the gas occurs principally in the pore spaces of the sandstone rather than in crevices, appears to be borne out by the location of the gas only on structural highs as well as by the porosity determinations. This conclusion raises an interesting question as to the probable location of other producing fields. Leaving out of consideration the application of the carbon-ratio theory to this problem, as we do not know the upper limit for commercial gas accumulation, it is evident that, in general, pore space in the Oriskany sand must decrease towards the southeast owing to the

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greater degree of metamorphism to which the rock formations have been subjected. With decreasing reservoir capacity, therefore, the probability of finding commercial quantities of gas becomes less. On the other hand, if fractures in the sandstone were the controlling factor in furnishing reservoir space for the gas accumulation, then well defined structural highs on the anticlines lying southeast of the Sabinsville structure would furnish favorable places for drilling, because the rock formations are more highly fractured in this direction.

To the northwest of the Sabinsville anticline the amount of pore space in the sand should be equivalent to if not greater than on that structure. The discovery of gas in the Hebron well, in Potter County, appears to support this conclusion. Well defined structural highs in this region should be given careful attention.

The most uncertain element, which can hardly be determined in advance of drilling, is the thickness and continuity of the Oriskany sand. However, since the Lamont and Derrick City deep wells reported sand and gas at about the horizon of the Oriskany sand it is possible that there is a more or less continuous layer of Oriskany sand having sufficient porosity and thickness extending from McKean County to the Tioga County gas field. Since the experience gained by the drilling in Tioga County shows the necessity for the careful location of wells on the highest part of anticlines, the Derrick City well does not necessarily condemn all of the Bradford structure.

The outcrop of the Oriskany sand south of the Tioga gas field is often inconspicuous due to checking of calcium carbonate from the formation, leaving a sandy argillaceous soil. Very little idea as to the porosity of the sandstone can be obtained by the study of outcrop samples and inconspicuous outcrops may also lead to erroneous conclusions as to the lack of continuity of the formation.

PYMATUNING RESERVOIR PROJECT*

By Charles E. Ryder†

THE PYMATUNING SWAMP

Pymatuning Swamp is located at the headwaters of the Shenango River in Crawford County, Pennsylvania, about 40 miles south of Lake Erie, 20 miles north of Sharon and near the Pennsylvania-Ohio border. It is an extensive morass covering an area of over 10,000 acres and was probably formed by the deposition of glacial drift over a preglacial lake or river-bed. What is called the Pymatuning Swamp may be divided into three distinct classes of land:

1. The swamp proper—a sometimes impenetrable, mucky bog, covered with grass, brush and timber, in the central part of the district adjoining the river and its main tributaries.

2. Low flat land submerged during considerable portions of the year, and traversable at other times, but which is waste land, largely covered with brush and timber.

3. Land periodically flooded, in some degree under cultivation, but generally devoted to pasturage or covered with brush and timber.

Bordering these lands are broad, sloping fields, suited to and largely under cultivation but containing many acres devoted to pasture and woodland. In the region of Linesville, Pa., in the north central part of the swamp, about 500 acres of morass have in years past been reclaimed by drainage ditches, and the rich, black muck successfully devoted to onion culture. In recent years, however, this land has been largely neglected, the muck has dried out and the land deteriorated, so that this once profitable business has been almost entirely abandoned.

The source of the Shenango River is 1050 feet above sea-level, the stream falling 30 feet in a quarter of a mile to the swamp, through which it winds westward for nine miles in a narrow, shallow channel through what was until a few years ago a tamarack and

*Presented March 1, 1932. Received for publication April 15, 1932.

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hardwood forest, being joined in this distance by Linesville Creek, Bennett Run and Paden Creek. It thence swings southward, traversing the swamp for four miles, emerging from the morass a short distance below the Espyville-Andover highway, and having an average slope through the swamp of 2.4 feet per mile. Below the swamp the course of the river is southeastward for about eight miles, to the site of the proposed dam, about a mile and a half above Jamestown, on the border line between Crawford and Mercer counties. The valley, for a little more than two miles above the dam, is narrow and then immediately broadens out to create an ideal site for a storage reservoir. The elevation of the river at the dam is 972 feet above sea-level. The tributary drainage area is 160 square miles.

The real storage existing in the present Pymatuning Swamp district is mainly in the porous sands which surround the shores of the swamp.

The change in the water-level of 46 wells, within and bordering on the reservoir site, was observed from February 1 to November 1, 1912, by engineers of the Water Supply Commission. The information collected afforded a fair indication of the conditions of the upper level of the ground water. From this study certain wells were selected for continuous observation, which was maintained until September 1918, and the effect of the fluctuation of ground water on stream flow was noted.

The soils within and surrounding Pymatuning Swamp are, in general, composed of silt, loam and fine clay, interspersed with broad plains of sand and gravel, as evidenced by the long sinuous ridges and glacial topography. From February 1912 to September 1918 the maximum fluctuation from the end of drought periods to the point of greatest rise was 11.6 feet. The average for groups of wells varied from six to seven feet.

The recovery of ground water supply in this region, following the droughts of 1930 and 1931, appears to be forecast by our recent observations, as the winter replenishment began about the first of December and by February 2 the ground water had risen on an average about 3.5 feet, which exceeds the ground water elevations in the same wells, observed in the period 1912-1918 for the same time of the year, by 0.5 of a foot to nearly two feet. This is no doubt due to the mild winter season, which permitted rain and snow

to enter the soil which is normally frozen during December and January.

The Water and Power Resources Board has numerous wells under observation throughout the state and it may be interesting to know that the average rise in ground water from the end of the drought of last year to February 1, 1932, is about 4.5 feet, the maximum rise recorded being 11.09 feet.

The Ohio basin, exclusive of the Pymatuning reservoir district, has had an average rise in ground water of 4.3 feet; the Susquehanna basin 4.8 feet; and the Delaware basin 4.2 feet. In comparison with these basins, partly within the glacial districts, the Pymatuning wells show an average rise of nearly six feet, of which 3.5 feet occurred in December and January.

As a large amount of water stored in the glacial deposits bordering Pymatuning reservoir will be released as the reservoir is drawn down to regulate the Shenango River, the information obtained from well observations is an important part of our hydrological work.

HISTORY

For many years there has been talk of draining the Pymatuning Swamp, and as early as 1868 the General Assembly of Pennsylvania passed a resolution providing for "a survey and estimate of expense of reclaiming certain bodies of land in the County of Crawford, known as the Conneaut and Pymatuning marshes, and a report, with plans and estimates, of the practicability and expense of the same, to the next Legislature." Col. James Worrall, a civil engineer, made the survey and reported favorably, but nothing further was done until the year 1907, when legislation was again enacted making an appropriation to the State Highway Department with which to make surveys of Pymatuning Swamp and determine upon the "best course and method of making channels for draining the same and improving the highways therein . . . provided, however, that the plans shall be approved by the Water Commission." Plans for the proposed drainage of the swamp were submitted to the Water Supply Commission for approval in 1909, following which hearings were held at which a number of protests were made on the ground that the swamp was a valuable storage area and helped to maintain the dry weather flow of the Shenango River. The hearings showed that

there was a large consumption of water from the stream, and an insufficient flow therein to meet the needs of the various communities adjoining it. It also indicated the possible injurious effect which might result from the drainage of the swamp, and, at the same time, the possible advantages of converting the swamp into an artificial storage reservoir for increasing the dry weather flow. As a result of its investigation the Commission refused to approve the plans as submitted and the Legislature, in 1911, passed an Act appropriating $10,000 to the Water Supply Commission, with instructions to examine into the feasibility of the reservoir project and to report to the Legislature of 1913, accompanying the report with plans and estimates of cost. Such a survey was made under the direction of Farley Gannett, then chief engineer, and the Commission reported to the Legislature on December 31, 1912, that it "has made a thorough topographical survey of the swamp and surrounding area, plotted the same to a scale of 300 feet to the inch, with 2 feet contour intervals, carefully investigated the proposed dam and reservoir site, examined conditions along the Shenango and Beaver rivers below said swamp, studied the hydrographic features by means of precipitation and stream discharge records and measurements, has prepared preliminary plans of the proposed work, has estimated the cost of the project, and has determined that the construction of a storage reservoir is feasible." It further reported that "As a result of this study, the Commission is assured of the desirability of its construction, and the feasibility thereof, the resulting benefits accruing to the State at large, as well as to the various communities along the stream." The site for the dam, selected under these original surveys, was at a point a little above the Turnerville bridge, which is about 1½ miles above the site finally selected after more careful exploration of surface and subsurface conditions at other possible sites in the valley. The total cost of the project, as estimated in the 1912 report—including the dam and spillway, changes in highway and railroad, purchase of land and buildings, clearing the reservoir site and improving the shores—was $1,556,402. As a matter of fact, it has turned out that the cost of the land alone, including the cost of acquisition and title examination, just about equals this preliminary figure for the cost of the completed project.

Following the receipt of this report, the Legislature in 1913 passed the "Pymatuning Dam Act," which directed the Water Supply Commission to erect a dam at the outlet of Pymatuning Swamp, for the purpose of establishing a reservoir to conserve the water thereof and to regulate the flow of water in the Shenango and Beaver rivers. This Act carried an appropriation of $100,000.

During subsequent sessions of the Legislature various other laws relating to the project were enacted, most of them carrying appropriations in varying amounts, but frequently containing provisions which made it impossible to use the money. For instance, the 1917 Act appropriated $400,000, subject to the provision that no portion of this amount should be available until the Commonwealth of Pennsylvania had full power and authority to submerge lands in the state of Ohio, nor until all property located in the state of Ohio and necessary in the opinion of the Water Supply Commission for the construction of the dam and reservoir had been transferred, clear of all encumbrances, to the Commonwealth of Pennsylvania. The result was that no money was spent for anything except engineering studies and investigations, the preparation of plans and the appraisal of the land, until the year 1921, when the first land purchases were made. Actual construction work was not started until ten years thereafter, when $1,500,000 was appropriated for the construction of the Pymatuning dam and spillway. The 1931 appropriation Act was amended during the special session of the same year so as to make this appropriation available for any necessary work or expense incidental to the completion of the project. In 1925 and 1929 the Legislature codified all previous general acts relating to the Pymatuning project, and the authority formally vested in the Water Supply Commission was transferred to the Department of Forests and Waters, acting through the Water and Power Resources Board.

The total expended by the Commonwealth, from the time of the first appropriation to the Water Supply Commission in 1911, until the 1931 appropriation became available, amounted to $1,164,105. Of this amount, $1,036,168 was used for the purchase of land and the remaining $127,937 for surveys and investigations, preparation of plans and appraisal of lands, and for administration, including the rental of lands acquired and the sale of timber and buildings.

I would estimate the total cost of the Pymatuning reservoir project, including the cost of the lands acquired in Ohio by private subscriptions (amounting to about $415,000), to be in the neighborhood of from $3,000,000 to $3,500,000. This estimate can not be exact, as it is difficult to predict the cost of clearing the land under methods now being used, and there is also some uncertainty concerning the ability of the foundation to support the highway fill which will cross the reservoir between Espyville and Andover. The cost of Pymatuning storage will amount to about $350 per million cubic feet, or $47 per million gallons.

PURPOSE

The primary purpose of the Pymatuning reservoir is to provide sufficient water during dry seasons of the year for domestic and industrial use in the Shenango and Beaver valleys, to improve sanitary conditions, and to control and reduce the height of floods in these rivers. This primary purpose is clearly indicated as the intent of the Legislature all through the Pymatuning legislation and is specifically stated as such in the 1931 amendment to the 1929 Pymatuning General Act. The 1931 law also provides that:

> "The reservoir and land surrounding it, acquired by the Commonwealth in connection with the project, or portions of such reservoir and land, may be developed and used for fishing, hunting, game refuges, recreation, park or other purposes; provided, such use or uses will not, in the opinion of the Water and Power Resources Board, materially interfere with the primary purpose of the reservoir for conserving the water entering Pymatuning Swamp and regulating the flow in the Shenango and Beaver rivers. The Water and Power Resources Board is vested with complete and final authority concerning the use and development of the land and water comprised within the Pymatuning Reservoir Project, and the maintenance and operation of said project."

This Act also provided that the Department of Forests and Waters, with the approval of the Water and Power Resources Board, "may enter into agreements with other Departments, Boards or Commissions of the Commonwealth of Pennsylvania and the State of Ohio, relative to the use of the reservoir and surrounding lands acquired in connection therewith, or portions thereof, for fishing, hunting, game refuges or other purposes."

Bordering the Shenango River, below the Pymatuning reservoir, are the towns of Jamestown, Greenville, Sharpsville, Sharon, Farrell, Wheatland, West Middlesex and New Castle, while both sides of the Beaver River are thickly populated and the banks lined with varied industries in the boroughs of Beaver Falls, New Brighton, Fallston, Beaver, West Bridgewater and Rochester. The distance from Pymatuning dam to the mouth of the Shenango River at New Castle is 64 miles and to the mouth of the Beaver River, 88 miles.

The Shenango valley is an active steel center in which an adequate and dependable water-supply is a prime essential. The growth of this industry has been retarded because of the scarcity of water during the summer and fall months and for the past twenty years the situation has been more or less acute. Water from the river is used over and over again during dry times and the temperature of the river water sometimes reaches 140 degrees F. During the summer months more than one-fourth of the flow of the Shenango River at Sharon and New Castle is pumped for domestic purposes, while the river water used by industrial plants is pumped from pools in the stream, returned to them and frequently reused. The flow in the river during the droughts of 1930 and 1931 was unusually low and, had the mills been operating during these years on a normal basis, the situation with respect to water-supply would have been acute indeed. The minimum recorded flow in the Shenango River at Sharon reached the extremely low figure of eight cubic feet per second, or 5,000,000 gallons a day. There is no doubt but that flows as low as this would mean the shut-down of many industrial plants along the river, and the fact that such low flows frequently occur has undoubtedly been the cause of diverting large manufacturing establishments away from the valley. By the same token, a dependable water-supply which, during the summer months, will never fall below 400 cubic feet per second, 50 times the recorded flow of eight second-feet, will attract industry. When the Pymatuning reservoir is built and in operation, I look for marked industrial expansion in the Shenango valley, as manufacturing plants will seek sites free from flood overflow and assured plenty of good water at all seasons of the year.

The location of the Pymatuning reservoir and the drainage area of the Beaver River and tributaries are shown in Fig. 1.

Fig. 1. Pymatuning Reservoir, and Drainage Area of Beaver River and Tributaries.

SANITARY CONDITIONS

The Beaver and Shenango rivers are the sources of supply of waterworks serving about 175,000 people, with intakes and filtration plants at Sharon, New Castle, West Pittsburgh, Eastvale and New Brighton. I am informed by the Department of Health that the load on the water filters in past years was steadily increasing due to the increased discharge of sewage to the rivers.

Recognizing the great menace to public water-supplies, as well as actual nuisance conditions in the Shenango and Beaver rivers, the Sanitary Water Board has required that sewage treatment works be installed by all municipalities discharging sewage into the Beaver River or any of its tributaries in Pennsylvania above the intakes of waterworks serving the public and, prior to assurance of the development of the Pymatuning project, the Department of Health considered it necessary that all public sewage discharged into the Beaver and Shenango rivers receive treatment, comprising oxidation, chemical disinfection, and removal of solids; but, in the final determination of its policy to require only chemical disinfection and the removal of solids from the sewage of these communities, the Sanitary Water Board has assumed that the Pymatuning dam project will make available additional water of dilution in the Beaver and Shenango rivers at periods of low stream flow and to conserve, to a reasonable degree, the water of these streams as fit sources of supply for water purification plants serving the public.

As a result of pressure brought to bear by the Department of Health and the Sanitary Water Board, as I am informed, sewage treatment works have been constructed to serve 17 of the 19 communities discharging sewage into the river and its tributaries in Pennsylvania. These communities along the main stream of the Shenango and Beaver rivers which have installed sewage treatment works are Greenville, Sharpsville, Sharon, New Castle, West Pittsburgh, Ellwood City, Koppel, and Beaver Falls. Plans for sewage treatment works for Linesville are in preparation. Plans for treatment works at Farrell have been completed, and a bond issue for construction of the works has been approved by the voters, but local objection has delayed actual construction of the works so that it has become necessary for the Sanitary Water Board to refer this matter to the Attorney General for appropriate action.

After the Pymatuning dam is placed in operation and the minimum stream flow at Sharon increased from eight cubic feet per second to 400 cubic feet per second, and with a reasonable allowance for reduction of the sewage load by sewage treatment works now constructed or required, and also making allowance for natural purification of the stream between points of sewage-effluent discharge, it is estimated that the resulting dilution factor at minimum stream flow below Farrell will be equivalent to approximately six to eight cubic feet per second per thousand of the sewage-contributing population, and at New Brighton, where the proportional increase will be less, it will be about 3½ to five cubic feet. The minimum factor ordinarily accepted to prevent nuisance, without allowance for reduction of the pollution load by sewage treatment and for natural purification of streams between points of sewage discharge, is four or five cubic feet per second per thousand of the sewage-contributing population, or more than ten times the dilution effective in the Shenango and Beaver rivers at the present time. The construction of the dam will, therefore, make it unnecessary, for many years, for the municipalities on these streams to construct units for refined sewage treatment works, which would cost probably about $2,000,000 more than the total cost of sewage treatment works now constructed or contemplated.

WATER-POWER

There is comparatively little use made of the Shenango and Beaver rivers for power development, although the proposed regulation of the flow and increase in dry times would benefit the existing water-powers, which are located principally on the Beaver River.

POWER POSSIBILITIES AT THE PYMATUNING DAM

The discharge of water from the Pymatuning reservoir to obtain a minimum flow of 400 cubic feet per second in the Shenango River, at Sharon, suggests the possibility of developing power at the dam, and studies have been made to determine whether or not this would be economically feasible. The flow of the released water varies greatly, from the storage periods when the flow of the Shenango River is above 400 cubic feet per second and no water is released from the reservoir for considerable periods of time, to the dry seasons when

water is released to practically the maximum amount of 400 cubic feet per second. Studies of probable discharge from the Pymatuning reservoir, had it been in operation, for the period from 1908 to 1917, inclusive, show that there could have been developed an average annual output of about 3,800,000 kilowatt-hours using an efficiency of 77 per cent.

There would, therefore, be long periods of time during the year when no power at all would be developed in such a plant, and when the plant was in operation it would be operated continuously 24 hours a day. The purpose of the Pymatuning reservoir, which is the regulation of the Shenango and Beaver rivers so as to increase low flows and reduce floods, precludes the possibility of releasing the water in such a manner that the power-plant could be used to develop what is termed "peak power" and the power would have to be used as developed, and is what is termed in the power industry as "dump power." Such power is said to be worth to the purchasing companies only the amount that would be saved in fuel and station operation. Its use is also said to decrease the efficiency of the companies' own generating stations.

It was estimated that it would cost about $65,000 to build a plant to develop the power at Pymatuning dam. This was for the substructure, including machinery, but did not include the cost of superstructure, overhead, or contingencies. The cost of the plant, including superstructure, overhead, etc., would probably be in the neighborhood of $100,000, and as the average annual output would be 3,800,000 kilowatt-hours, and the market price for "dump power" is but one-tenth of one cent per kilowatt-hour, it is not economically feasible to develop power at this time.

The maximum power at the dam, with water at a level with the spillway and a discharge of 400 second-feet, is 1220 horse-power at 77 per cent. efficiency. The approximate cost of producing "dump power" would be about ¾ mill per kilowatt-hour without any allowance for interest, depreciation, or taxes.

Notwithstanding the fact that power development at the dam is not economically feasible at this time, the plans of the dam are so drawn as to make such installation possible at any future time by the construction of a power-house at the lower end of the outlet conduits.

FLOODS

The greatest benefit to be derived from the construction of the Pymatuning reservoir will be in the increased supply of water for domestic and industrial purposes, rather than through flood control, for the two purposes require different kinds of regulation of the impounded water. A full reservoir is most to be desired for water-supply, while for flood regulation an empty one would be ideal, as evidenced by the retarding basins built for flood protection in the Miami valley in Ohio. However, the purposes may be combined without sacrifice to the higher need of the reservoir for supplying water for domestic and industrial use, as the capacity of the lake will be sufficient to absorb and hold back most of the flood flow entering it until the flood waters from the valley below the dam have passed down-stream and the river receded again to below flood level.

Damaging floods in the Shenango and Beaver valleys are of frequent occurrence, although there is little authentic reference with regard thereto prior to 1884. Records seem to indicate that the greatest floods occurred in the years 1806, 1832, 1884, 1893, 1910, and 1913. The extraordinary flood of March 26, 1913, wrought much injury throughout Ohio and Western Pennsylvania, devastating populous valleys, particularly at Dayton and Columbus, Ohio, and at Sharon, New Castle, and Beaver Falls, Pa. The estimated damage from this flood in the Shenango and Beaver valleys exceeded $2,000,000, so that the loss from this flood alone would go a long way towards building the Pymatuning reservoir.

Had the reservoir been in operation during the 1913 flood, the crest would have been reduced 3.9 feet at Sharon and two feet at New Castle. The flood height at Sharon would have been reduced by 23.3 per cent., and the maximum rate of discharge 32.5 per cent.

NAVIGATION

The regulation in the flow of the Shenango and Beaver rivers, which will be afforded by Pymatuning reservoir, will benefit navigation in these streams should they be improved for this purpose as at present contemplated. The Water Supply Commission and the Water and Power Resources Board have always had in mind that these streams might at some future time be made navigable, and they have been familiar with the plans for developing a waterway between the

Ohio River and Lake Erie. In order that the two projects might be harmonized and the Pymatuning project made to fit into the plans for developing such a waterway, a special study was made for the Commission by its then consulting engineer, Mr. Frederic P. Stearns, of Boston. He made his report (upon the joint project for regulating the discharge of the Shenango and Beaver rivers and supplying water for the Lake Erie and Ohio River canal) to the Commission in 1917. It was his conclusion that if the two projects were to be carried out there should be co-operation by those in charge; that it was desirable, if not essential, that the supply of water for the canal should be chiefly French Creek water stored in an enlarged Pymatuning reservoir, and that, if the additional works for the purpose were adequate, the regulation of the Shenango and Beaver rivers would be more satisfactorily accomplished by the joint works than with independent works. He was satisfied that the nearly 14,000,000,000 cubic feet estimated to be required for canal uses during each navigation season, even if the canal were given the largest of proposed dimensions and double locks, could be obtained from French Creek, Mill Creek and Mosquito Creek if sufficient storage capacity were provided in the Pymatuning reservoir and elsewhere. Such works would provide during the driest periods, and with a large margin for contingencies, the above quantity of water for canal uses, and all the water required for maintaining a discharge of 450 cubic feet per second in the Shenango River. The works Mr. Stearns proposed included:

1. Reservoir "A" on French Creek with a capacity of 2,130,000,000 cubic feet. This reservoir was to be built about three miles below Kimmeytown and to be the farthest down-stream of four large reservoirs on that stream found feasible by the chief engineer of the Canal Board in his studies, and one of those investigated by the Flood Commission of Pittsburgh and described by it as Reservoir project 16.

2. Diversion dams across French and Cussewago creeks, about 2½ miles above Meadville, with an interconnected reservoir above them. It was proposed to fix the flow-line of this reservoir at elevation 1095, which would give a storage of 390,000,000 cubic feet above the normal flow-line of the

proposed feeder canal at the reservoir, and about 720,000,000 cubic feet above the minimum flow-line.

3. A feeder about 20 miles long, from the diversion dams at French and Cussewago creeks to the Pymatuning reservoir, having a winter capacity of 1000 cubic feet and a summer capacity of 1200 cubic feet per second. This feeder would be a canal about 30 feet wide on the bottom, with side slopes 1 vertical on 2 horizontal, with a depth of water of 11.5 feet.

4. A Pymatuning reservoir with a flow-line at elevation 1020, or 12 feet higher than that required for the regulation of the Shenango and Beaver rivers. This enlarged Pymatuning reservoir would have an area of 39.35 square miles, with a capacity of 19,440,000,000 cubic feet of which amount 18,000,000,000 cubic feet would be available.

5. A feeder about 14 miles long, leading from the Pymatuning reservoir to the head of a reservoir on Mill Creek having a capacity equal to the canal demand.

6. A reservoir on Mill Creek having an available capacity of 460,000,000 cubic feet.

7. A feeder about 11 miles long, leading from this reservoir to the summit level of the canal.

For the purpose of regulating the flow in the Shenango and Beaver rivers, the height contemplated for the Pymatuning reservoir is elevation 1008, and the capacity of the reservoir at this elevation is 8,593,000,000 cubic feet, all of which would be available in case of necessity for discharge into the river below the dam.

Raising the reservoir 12 feet to elevation 1020 adds to this capacity 10,870,000,000 cubic feet, making a total of 19,463,000,000 cubic feet; but, as the feeder leading toward the canal is higher than the bottom of the reservoir, there would become unavailable substantially 1,463,000,000 cubic feet of bottom water, which diminishes the total available capacity of the reservoir to 18,000,000,000 cubic feet. The net addition to the *available* capacity would be therefore 9,407,000,000 cubic feet.

Mr. Stearns reported that it might seem from this computation that the only storage available for canal purposes would be the 9,407,000,000 cubic feet added to the available storage, but the combined system could be operated to the advantage of both interests so as to make the storage available for canal purposes much more than this quantity. The reason for this is that so large a quantity of storage as 8,593,000,000 cubic feet is necessary for the independent project of regulating the flow of the Shenango and Beaver rivers only because of the comparatively small drainage area supplying the reservoir. The discharge from this area will not fill the reservoir each year, and consequently there has to be sufficient storage to equalize the discharge over a series of dry years, while with a larger supply to the reservoir which would be made available by constructing adequate works for diverting water from French Creek the filling of the reservoir each year would be practically assured. With the reservoir full each spring, less storage capacity would be required for river regulation and more would be available for canal purposes.

When an appropriation became available in 1931 for constructing Pymatuning dam, cognizance was taken of the fact that the reservoir might at some future time need enlarging for canal or other purposes, and the dam was designed with that end in view. The Water and Power Resources Board believed that it would not be proper to increase the cost of the dam materially to accomplish this purpose and it was found that this would not be necessary. The dam can be raised at any time without difficulty by adding earth on the down-stream side of the embankment, and the bridge over the spillway will be built so that it can be lifted to such additional elevation as may be required. It was deemed advisable, however, to increase the length of the outlet conduits in a down-stream direction to meet the toe of the added embankment, as the cost of such work at this time would be comparatively slight in comparison with what it would amount to later on, because of the control works to check the velocity of the water at the lower end of the tubes.

PYMATUNING RESERVOIR

The Pymatuning reservoir is shaped like an inverted letter L, the long side extending in a north and south direction and the short side toward the east. The elevation of the flow-line will be 1008 feet above sea-level and the capacity of the lake at this elevation will be

8,593,000,000 cubic feet, or 64,275,000,000 gallons. It will submerge an area of 16,420 acres, or 25.7 square miles. The lake will be 16 miles long and 1.6 miles in average width. The maximum width will be 2.2 miles, at which location a highway will be built crossing it in an east and west direction, connecting the towns of Espyville, Pa., and Andover, Ohio. The lake will have a shore-line of 70 miles and a maximum depth of 35 feet. About one-quarter of the lake will be in the state of Ohio. Fig. 2 is a map of the proposed reservoir.

About 25 miles of township highways will be submerged, 20 miles of which will be vacated and the remaining five miles raised or relocated. It will also be necessary to raise 2½ miles of Pennsylvania Railroad embankment, which crosses the northern end of the Pymatuning Swamp south of Linesville. This embankment, with that for an adjoining highway, will constitute a secondary dam; and the portion of the reservoir to the east, comprising 4700 acres, will be maintained at a constant elevation of 1009 or 1010 feet and be devoted to a migratory bird refuge, or sanctuary for all forms of wild life. This portion of the reservoir will be left in its present wild state and no clearing of any kind will be undertaken. This is in accordance with the advice of Governor Pinchot, the Board of Fish Commissioners, the Board of Game Commissioners, and others interested in conservation of wild life. This portion of the reservoir will be shallow and the storage capacity slight, so that the loss in regulating capacity of the river will be comparatively small.

Pymatuning Swamp has long been known as a paradise for birds and other forms of wild life, as well described by George M. Sutton in his paper, "The Birds of Pymatuning Swamp and Conneaut Lake, Crawford County, Pennsylvania."* There are records of 244 different species of birds having been seen in this area, all of which are summer residents. Mallards, black ducks and pintails make their winter home here and fur-bearing animals are numerous.

The Pymatuning reservoir will cover an area nearly three times as great as Lake Wallenpaupack in Pike and Wayne counties, which is now by far the largest lake in Pennsylvania. The water surface of Pymatuning Lake will be almost 3000 acres greater than that of

*Annals of the Carnegie Museum, 1928, v. 18, p. 19-239. Pittsburgh.

Fig. 2. Map of Pymatuning Reservoir.

Chautauqua Lake in New York State and it will be almost 18 times the size of Conneaut Lake.

APPRAISAL AND PURCHASE OF PYMATUNING LAND

A preliminary appraisal of the value of the property to be acquired was made in 1914 by the engineers of the Water Supply Commission, who made surveys of the properties. The final appraisal, used as a basis for negotiating purchases, was made by a commission, called the Pymatuning Reservoir Project Appraisal Commission, appointed by the Water Supply Commission in November 1920. This appraisal commission consisted of W. A. McMasters, President of the Jamestown Banking Company, Jamestown, Pa., Chairman; John E. Reynolds, President of the Merchants National Bank, Meadville, Pa.; Harry McDowell, President of the McDowell National Bank, Sharon, Pa.; Daniel L. Bunnell, President of the Linesville State Bank, Linesville, Pa.; and George S. Beal, an engineer representing the Water Supply Commission. This commission, late in November and early in December 1920, visited and appraised the land and buildings on various properties in the area to be acquired.

In the appraisal of values, the land on the different properties was divided into different classes according to its use:

1. Onion land, which was the most valuable class of land in the flooded area.
2. Cultivated land other than onion land.
3. Pasture.
4. Woodland.
5. Swamp.

The properties were marked off into groups of similar character, as to quality and value of land, on an index map of properties to be acquired. The classification of the land and the grouping were carried out by the engineers of the Water Supply Commission, who were familiar with the ground from the preliminary appraisal and from surveys. From one to five properties in each group were visited and examined to determine the values of land to be used in each group, the values fixed being based on the knowledge of the members of the

commission as to such values, and on recent sales, either in the group in question or in its immediate neighborhood. The values thus determined did not include the value of the buildings nor the value of the timber, which were determined separately.

The values of the improvements were determined by visiting the various properties, and were based on recent sales in the neighborhood, types of buildings, character of construction, and condition at the time of the appraisal. These improvement values were not the cost of replacing the structures in question. Timber values were based in part on a timber survey made in 1914 by engineers of the Water Supply Commission, and partly on a survey made in 1912 by representatives of the Forestry Department. The stumpage value of timber used was $10 per thousand feet board measure.

The results of the appraisal were submitted to the Water Supply Commission in tabular form, the tables containing the following information:

1. Property index numbers referring to the property index map showing location of the properties.
2. Names of owners arranged alphabetically.
3. Information regarding deeds, including book and page where recorded, date, consideration, and area.
4. Assessed valuation of land and buildings in 1920.
5. Area of property by surveys in 1914, and township where property is located.

Two complete valuations were made, one for the "minimum area required," which was the minimum area considered necessary for reservoir purposes to elevation 1014, and another for the "maximum area required," which included, in addition to the above, tracts which would be cut off from the remainders of the properties by reason of the flooding of lands, and, in some cases, entire farms where it was thought that the owners would desire to sell the whole properties rather than parts.

Each valuation included the amount of land of each class required, the percentage of the whole property taken, land value, improvement value, timber value, total value, and value per acre.

All computations of acreage and detailed computations of valuations were made for the Appraisal Commission by engineers of the Water Supply Commission.

This appraisal was reviewed by Mr. George E. Etter, of Harrisburg, a real-estate expert who had been employed by the state in connection with the acquisition of land for the Capitol Park Extension in Harrisburg. His conclusion was that the appraisal had been made fairly and honestly, and was, on the whole, conservative. The appraisal was also reviewed by Mr. Edward Sauer, who had charge of the appraisal of seven or eight million dollars worth of land purchased by the Miami Conservancy District, and of the appraisal of about 70,000 tracts which were assessed for benefits in that district, and in his judgment the values fixed for each individual parcel were approximately correct. Mr. Arthur E. Morgan, chief engineer of the Miami Conservancy District, considered the appraisal on the whole as thoroughly well made.

The "maximum area required" was estimated to be 19,260 acres, which was valued by the Appraisal Commission at $1,002,450, including buildings and timber, or at the rate of $52.05 an acre. Up to the present time 19,400 acres have been purchased for $893,805, or an average cost of $46.07 an acre. There still remain about 650 acres to be purchased.

Where the purchase of a flooded portion of a farm would cost nearly as much as the whole tract of land, it was all bought. This was found to be the case in many instances where the portion required would leave remaining an area too small for farming purposes and therefore practically valueless to the owner. Up to the present time it has been found necessary to institute condemnation proceedings in connection with only four tracts of land, containing 181 acres. In all but one case, after the finding by the viewers, the purchase was completed by agreement at reasonable prices. The remaining tract was also purchased by agreement following a jury award and appeal by the state.

LAND IN OHIO

A little over 5000 acres of land in Ohio, necessary for the project, were acquired at a cost of over $400,000 by private interests, principally steel companies, of the Shenango valley, who organized an Ohio corporation, the Pymatuning Land Company, to hold this

property. This Ohio property was all bought before any land was purchased in Pennsylvania, and, on October 9, 1922, the Pymatuning Land Company gave the Commonwealth of Pennsylvania the right to flood this property with the spillway of the reservoir not higher than elevation 1010. The Department of Justice of Pennsylvania has approved this easement and right of flowage.

An enabling act was passed by the Ohio Legislature in 1929, authorizing the flooding of the Ohio land, provided that Pennsylvania secured the proper releases from the owners of the land, and that the public roads of Ohio affected be relocated or reconstructed at Pennsylvania's expense in accordance with plans approved by the proper Ohio authorities. This includes the highway east from Andover, which is to be a hard-surfaced road, along which proper guard rails are to be erected and maintained. Pennsylvania is also authorized to relocate or reconstruct, by and with the consent of the owners, any public-utility line or lines in flooded area with the consent of the property owners affected and the approval of the Public Utilities Commission of Ohio, where necessary. This law also creates as a special sanitary district the area of Ohio in the reservoir and extending back one mile therefrom.

The total purchases for the Pymatuning reservoir project when completed will amount to the following:

	Acres
Area in Pennsylvania	20,050
Area in Ohio	4,740
Total	24,790
Area to be flooded	16,730
Area not flooded	8,060

This liberal, but required, purchase of land has resulted in the state of Pennsylvania now owning all the land bordering the whole area lying in Pennsylvania which will be flooded. It will make available about 8000 acres of land surrounding the lake which can be turned into a state park or otherwise devoted to recreational, forestry, or other desirable purposes. It has been the policy of the Water and Power Resources Board to refuse to sell any land which has been acquired, although it will no doubt lease portions of it in certain

locations for cottage sites, for camps and for other purposes which may best suit the development of the project, and which are not incompatible with the state's interest and the public good. The lake will be bountifully stocked with fish by the state.

RENTAL OF FARMS AND SALES OF BUILDINGS, CROPS, AND TIMBER

In the earlier stages of the project, as farms were purchased, the former owner was allowed to remain on the farm, rent free, until the following April, and in some cases for an additional year, provided he paid the taxes for that year, after which he paid an annual rental. The rental rates were low because the tenant was required to make all necessary repairs to the buildings and fences. In cases where extensive repairs were necessary, the tenant was allowed a reduction in rental to compensate for this. Later, in the purchase of properties, the former owners were required to surrender the farms to the Commonwealth on the following April 1 and all taxes were assumed by the state. Some tracts and portions of others above a specified elevation are still rented, and will be until the end of 1932, or until the reservoir is filled or the land required for other purposes.

The total amount thus far received from the leasing of farms is $51,305. This money can not be used for the project, but goes into the general fund of the Commonwealth.

Many buildings not needed by the tenants, and those on tracts not rented, have been sold. The amount received from this source is $4340. From the sale of fruit, hay and other crops on lands not rented, $470 has been realized.

Owing to the fact that a large part of the timber is in swampy areas and other stands are small and in isolated sections, it has been difficult to sell, and the amount received from this source is only $8650. In most cases the desirable timber was cut before the tracts were acquired by the state.

The total amount received from the rental of farms and the sale of buildings, crops and timber is $64,765, of which $18,700 was used for the purchase of land and other needs of the project and the remaining $46,065 has been turned into the general fund of the Commonwealth.

Existing laws provide that taxes on lands acquired by the Commonwealth for the construction of Pymatuning reservoir shall be paid by the Commonwealth. County, township and road taxes are paid from the general fund of the Water and Power Resources Board, while school taxes are paid from funds appropriated to the Department of Public Instruction. These taxes are based on the assessed valuation of the land at the time of the purchase, which valuation may not be increased. Taxes paid by the Board for the year 1931 amounted to $10,048.84, and the total amount of taxes paid by the Board to date is slightly less than $37,000.

RECONSTRUCTION OF HIGHWAYS AND RAILROADS

Two sections of highway and one section of railroad within the Pymatuning basin will have to be raised to place them well above the reservoir level and to take care of wave action. This work will cost almost twice as much as the construction of the main dam, and it is expected that contracts for this construction will be let so that the work can be completed this year.

ESPYVILLE-ANDOVER HIGHWAY

A township road now crosses the Pymatuning Swamp near the center of the proposed reservoir in an east and west direction, connecting the village of Espyville, Pa., and Andover, Ohio. It will be necessary to raise this highway by the construction of an embankment about 2½ miles long and having a maximum height of 32 feet. This embankment will be built of material hauled to the site and will be placed in layers and rolled, following closely Highway Department specifications for such work. The side slopes will be 1 vertical on 2 horizontal, and they will be faced with heavy paving or riprap to protect the embankment from wave action. A suitable bridge will be built at a point east of the present Shenango River crossing, at a point where sandstone rock lies comparatively close to the surface of the ground. The highway will be elevated at the bridge, so as to provide a clearance of 20 feet for the passage of boats.

Borings were made across the valley along the center-line of the road for the purpose of determining subsurface conditions. From these borings it was found that sandstone rock occurs at a depth of from 15 to 20 feet below the surface at both the eastern and western

ends of the valley, but that this rock dips to a depth of more than 80 feet below the surface over a length of about a mile in the center of the valley. The soil immediately below the surface of the ground consists of brown sand and clay, averaging in depth from five to 10 feet, below which is about an equal depth of a fine, gray sand containing some gravel; below this to the rock the material consists of a very fine, gray, silty sand or rock powder.

The engineers of the Board do not anticipate difficulty in the construction of an embankment to the height proposed on this foundation, but in view of the experience of the State Highway Department in constructing a fill across the Conneaut Swamp, we have decided to build a test section of fill to determine the ability of the foundation to support the load. This test section of fill will be built to full dimensions and will have a length on top of 200 feet. The test section of fill will be placed at a location where foundation conditions seem to be most uncertain, and it later will be made a part of the finished highway, so that the cost of the completed work will be only slightly increased by reason of its construction. We are not looking for trouble and, therefore, have not considered, except in a general way, other methods for carrying this road across the valley. A concrete viaduct has been suggested in place of the embankment, but this method of construction would appear to be inadvisable, unless foundation conditions make it necessary, because of the action of ice upon such a structure.

Plans and specifications for the test section of fill have been completed and the Board is about ready to advertise for bids for this work.

RAILROAD AND HIGHWAY RECONSTRUCTION SOUTH OF LINESVILLE

The Pennsylvania Railroad crosses Pymatuning Swamp in a north and south direction immediately south of Linesville, and this railroad is roughly paralleled by a township road, which crosses the railroad at grade at three locations within a distance of a little over a mile. The present elevation of the tracks is approximately 1010 feet above sea-level, so that it will be necessary to raise the road-bed eight or 10 feet to place it well above the flow-line of the reservoir.

The highway similarly is low in places and must be raised to the same elevation as the railroad.

Present plans call for the construction of an embankment which will support both the railroad and the highway, and for the elimination at this time of at least two of the grade crossings. This proposed improvement will be carried over a distance of approximately 8000 feet.

The Shenango River and Linesville Creek pass under the railroad and highway within 4500 feet of each other, and as the elevation of the reservoir above or east of the railroad will be maintained at an approximately constant level it will be possible to divert Linesville Creek so that only a single bridge will be necessary at or near the present bridge location over the Shenango River. The joint highway and railroad fill, or at least a portion of it, will be designed as a dam to hold the water in the upper section of the reservoir, and outlet and regulating works will be constructed between the abutments of the bridge.

The plans for this proposed work have been submitted to the State Department of Highways and have been approved. They have also been submitted to the Pennsylvania Railroad Company and are now being studied, with particular reference, as I understand it, to railroad alinement and the elimination of the third grade crossing immediately south of Linesville. A contract for making borings along the line of railroad and highway has been let, and it is my understanding that the results of these borings will be available to the Board and the Railroad Company within the next week or two. The Board expects that an agreement can be reached with the Pennsylvania Railroad Company and contracts let so that the railroad and highway elevation can be undertaken during the present year.

CLEARING RESERVOIR SITE

When the remainder of the appropriation of $1,500,000, not needed for the construction of the Pymatuning dam and spillway, was made available at the special session of the Legislature in 1931 for the reconstruction of roads and railroads, clearing the reservoir area, and other work incidental to the completion of the project, it was with the understanding, as I have been led to believe, between the Governor and members of the Legislature interested in the project, that this money would be utilized so as to afford the greatest amount

of unemployment relief consistent with a reasonable degree of efficiency in carrying out the work. It had always been the intention of the Board that the clearing of the reservoir site should be advertised and the work let by contract, as it believed that this method of procedure would be more economical than to undertake it with its own forces. It was realized, however, in view of the situation existing at the time the appropriation became available, that a greater degree of control could be exercised in the matter of relief to the unemployed if the clearing work were undertaken by the Board and, under directions from the Governor, the Board proceeded to organize the work upon this basis.

The State Highway Department had previously been undertaking highway construction with the same purpose in view by the construction of roadside camps in various parts of the state, and it was decided to organize the clearing forces at the Pymatuning reservoir upon a somewhat similar basis. In the organization and development of this work, the Board has had the active co-operation of the Department of Military Affairs, the Department of Health, and the Department of Labor and Industry.

The first step taken was the selection of a competent man to place in charge of this work, and the Board was fortunate in having in its organization an engineer with practical experience in timber and construction work, who appeared to have the necessary qualifications for a successful administration of this difficult job. This man is Mr. R. J. Ferris, a Cornell University graduate, who has been connected with the Pymatuning project most of the time since its inception, and who was particularly successful in handling the acquisition of the necessary lands and in administering the project from our district office at Linesville. The Board has also received valuable advice from its resident engineer in charge of the construction of the dam, Mr. C. C. Chambers, who has had experience in clearing reservoir basins in other sections of the country.

The Secretary of Health, Dr. Theodore B. Appel, who is a member of the Water and Power Resources Board, offered the services of Mr. Coleman B. Mark, construction engineer for the Department of Health, who had previously been assisting the Department of Military Affairs and the Highway Department in the construction of roadside camps.

The first step undertaken was to view the Pymatuning area and to select sites for the necessary camps, with the expectation that approximately 1000 men could be engaged at one time in the clearing work. In the selection of such camps, it was necessary to determine the limits of the area which could advantageously be worked from each camp; to determine whether a water-supply was available or could be furnished by the construction of drilled wells; to find out whether electric light and power could be secured without excessive cost; and to decide on locations which were accessible, as the roads generally within the Pymatuning area are impassable during the winter and spring months. As a result of this preliminary survey, it was decided to construct the main camp, to house approximately 150 men, along the Espyville-Andover highway at the eastern side of the proposed reservoir basin. A second camp of the same size was suggested along the Westford road about half way between Espyville and the dam site. Sites for a third and fourth camp were believed to be available at the extreme northern end of the proposed reservoir about three miles northwest of Linesville and at a point along the highway about two miles south of Linesville. It was further decided to use local labor to clear the area between the dam and the limits of the clearing operations working out of the Westford camp.

It was later decided to modify this original lay-out, and under present plans the two upper camps will not be built, principally on account of the fact that it will be difficult and expensive to obtain adequate water-supplies and to carry electric current to the proposed sites. After careful study, it was determined that it would be more economical and much more advantageous to increase the size of the camp at Espyville, and to transport the force which will work in the northern end of the area by means of trucks, which will be made available, without rental cost, by the State Highway Department.

Tents for housing the men, mess tents and all necessary equipment have been furnished by the Department of Military Affairs. The camps were constructed under the direction of Mr. Ferris, with the able and valuable assistance of Major Mark, of the Department of Health. The main concentration camp is at Espyville and a wooden office and administration building was constructed at this location. A doctor representing the Health Department was also located here and a hospital tent built to take care of the sick and

injured. This camp, as first constructed, provided quarters for 200 men and it is now being enlarged to twice its original capacity. The Westford camp has also been completed and has a capacity of 200.

Registration of the men who will be employed in the clearing work was handled under the general direction of Mr. A. W. Motley, an agent of the State Department of Labor and Industry. It was decided that the area from which labor should be drawn should be limited principally to the counties within the drainage basin of the Shenango and Beaver rivers and to counties bordering this area. Registration was conducted at Espyville near concentration camp No. 1, and at Conneaut Lake, Erie, Sharon, New Castle, Rochester, Warren, Bradford, Corry, and Kane. The registration card contains the name and address of the applicant, the number of his dependents, length of time without work, source of aid if any has been had, and other information of this character which would make it possible to judge of his capacity and need of employment. In each county a committee has been formed, consisting of welfare and other agencies, and this county committee is headed by a chairman, who represents the county and is the sole source of contact between the county agencies, the representative of the Department of Labor and Industry, and the Water and Power Resources Board, in the selection of men to be given employment. There is a member of this county committee representing each community in the county. The total number of registrations to date is 9774 and the number of men who have been placed and are now on the job is 415.

After a man has been selected and reports to camp No. 1 for work, he is first given a health and fitness examination. In accordance with an opinion received from the Attorney General, only native-born or naturalized citizens are employed. Men must show proof of vaccination or be vaccinated before going to work. Typhoid inoculation is optional and most of the men are taking it. All of these examinations and the services rendered by the doctor in charge of the camps are free to the men.

Each camp houses six men and is provided with a matched wooden floor and a three-foot wooden side wall. The tents contain a coal-burning stove and electric lights, and each man has an individual army cot with a bedtick filled with straw and four heavy army blankets. An ample supply of pure tested water is available for all

purposes and the bath-house contains both hot and cold water for washing and shower-bath purposes. Three good, wholesome meals are served each day, and for these a charge of 85 cents is made, which pays for the three meals and the cost of maintaining the tents with heat, light and other service. Records so far indicate that the men in the camps have gained from four to 10 pounds each in weight. Sanitation of the camps is under the supervision of Major Mark, while the conduct of the men is carefully watched by representatives of the state police from the Butler barracks, who live at the camps. Camp managers have been selected from officers in the National Guard, who are responsible for equipment, food, and housing of the men.

At each camp is a camp foreman responsible for the clearing operations in his area, and under each camp foreman there are six woods or clearing foremen assigned to definite areas. These woods foremen are experienced men and have been carefully selected, as each has charge of a squad of 30 men who are mostly inexperienced in woods work. A general foreman assists Mr. Ferris in the supervision of the work at all of the clearing centers.

The trees are cut, trimmed out and the merchantable logs sawed in full log lengths, which, if possible, will be sold as they lie on the ground. The remaining brush, poor trees, fallen trees, and branches are placed in piles and burned.

The first crew of 30 men started work on January 11, 1932, and the force has been gradually increased until at this time there are over 400 men working on the clearing. Upon completion of the addition to camp No. 1 within the next week, 200 additional men will be employed and hauled in trucks to the sites to be cleared in the swamp area west and south of Linesville. The clearing force of 90 men working north of the dam go back and forth to work each day from their homes. The men work nine hours a day and receive a wage of 35 cents an hour, with a deduction of 85 cents a day for maintenance.

At this time about 2000 acres of the Pymatuning area have been cleared, of which an area of about 500 acres consists of woodland. This woodland varies in the stand of timber from a few trees to more than 50 trees an acre, with a thick covering of brush intermixed with the trees. Progress of the work has been handicapped consid-

erably by high water and unfrozen ground, and areas usually accessible during the winter months are either ponds or swamps. The cost of the actual clearing work to the last pay-roll period on February 15 was approximately $16,500, and this cost may be divided into $9000 for the cutting, $500 for hauling, and $7000 for burning.

The camp turnover from January 11 to February 15 was 42 men to maintain the full camp strength, averaging, during this period, 325 men. Of this number 15 quit voluntarily, giving no reason; six reported that the work was unsatisfactory to them, seven secured other work or returned to their former jobs, one went home owing to an emergency, six left because of ill health, four were found to be unnaturalized, and three were discharged for insubordination and laziness. Of the 90 local men who live at home and travel to work, none has been lost for any reason.

Before the work started, it was anticipated that there would be many injuries, due to inexperience of the men in woods work and in handling axes, wedges, and saws. As a matter of fact, however, remarkably few accidents have occurred to date, and those which have occurred were not serious. There have been a few cuts from axes and a head wound caused by a flying wedge, some infections from thorn scratches, and an occasional poison ivy case. Generally, the sanitation and health of the men has been satisfactory, although there have been quite a few cases of colds, probably due to the fact that the men were not acclimated to camp life. None of these conditions has resulted in losing more than one or two days and it has not been necessary to hospitalize any patient.

PYMATUNING DAM

The Water Supply Commission in 1919 engaged Mr. Frederick P. Stearns, of Boston, consulting engineer, to prepare plans and specifications for the construction of the Pymatuning dam.

At the site selected, a shale rock is found near the surface of the ground at the right or west end. This rock dips to the left or east at a more rapid rate than the surface of the ground and continues dropping off under the left hillside, the overburden being a clay soil on the right hill, fine sand in the bottom of the valley, and coarse sand and gravel in the left hill. Test holes showed that this rock was about 25 to 40 feet below the surface across the bottom of the valley,

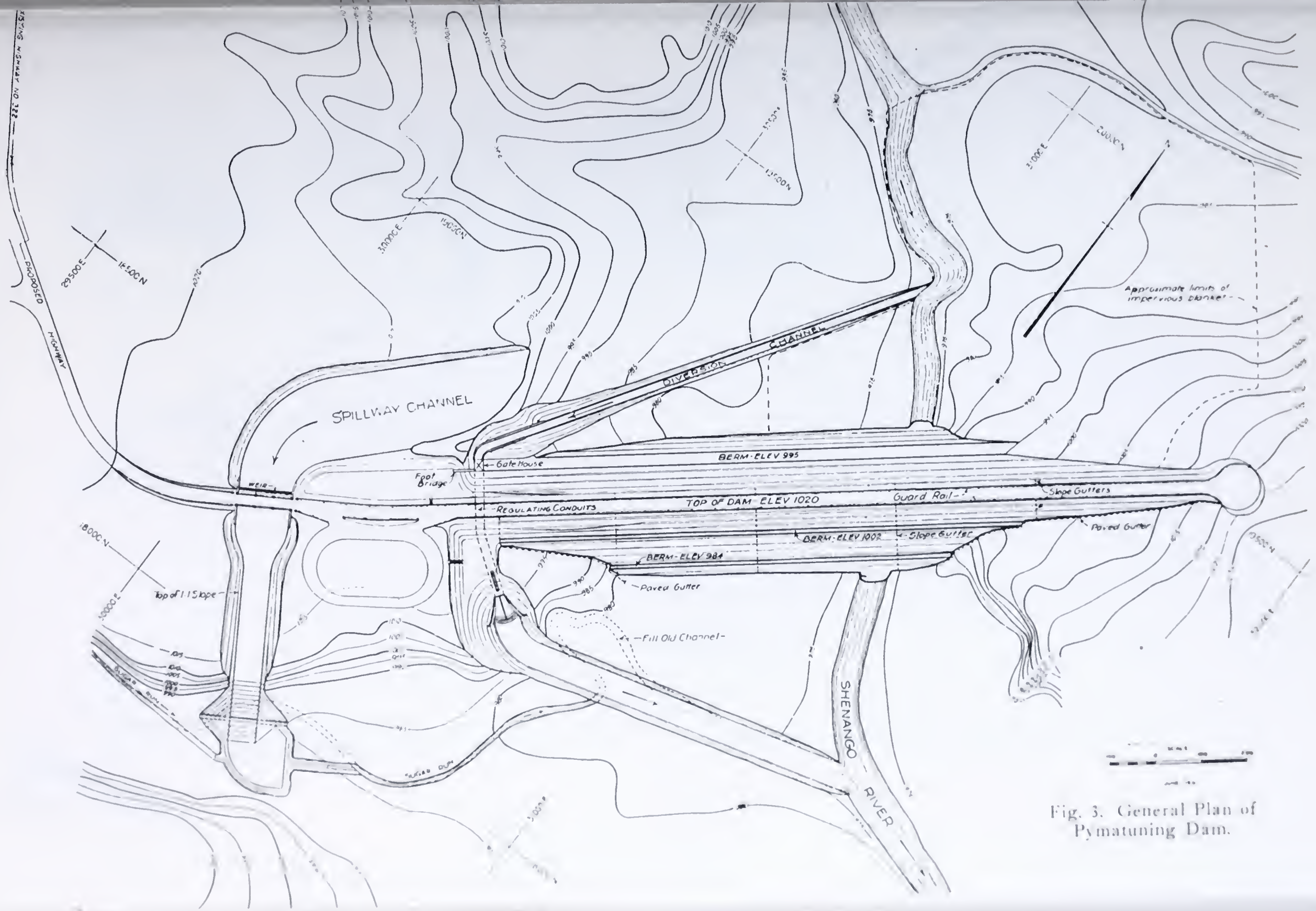
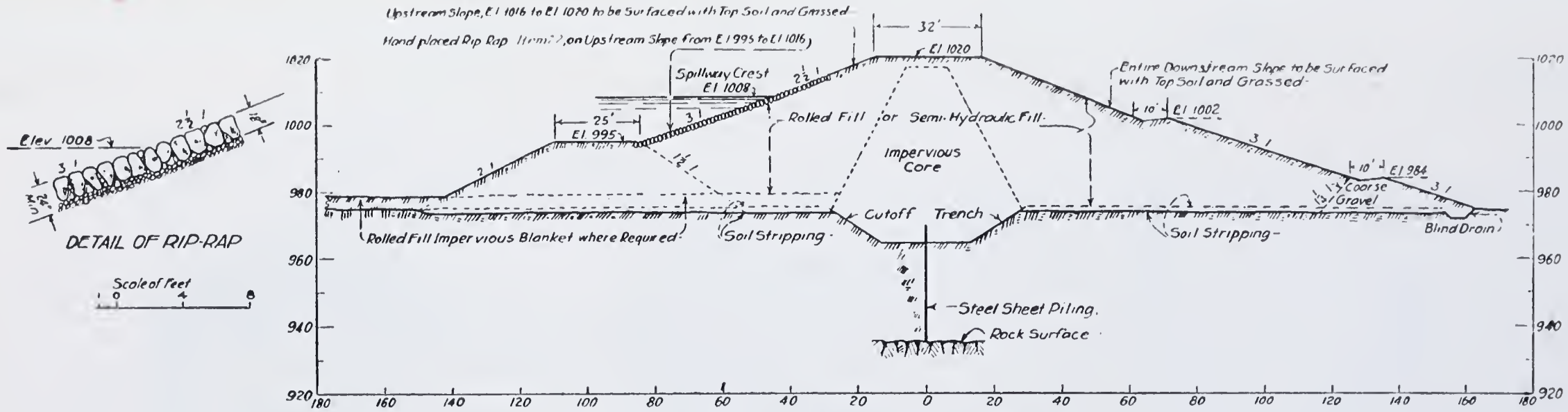


Fig. 3. General Plan of Pymatuning Dam.



TYPICAL CROSS SECTION OF DAM

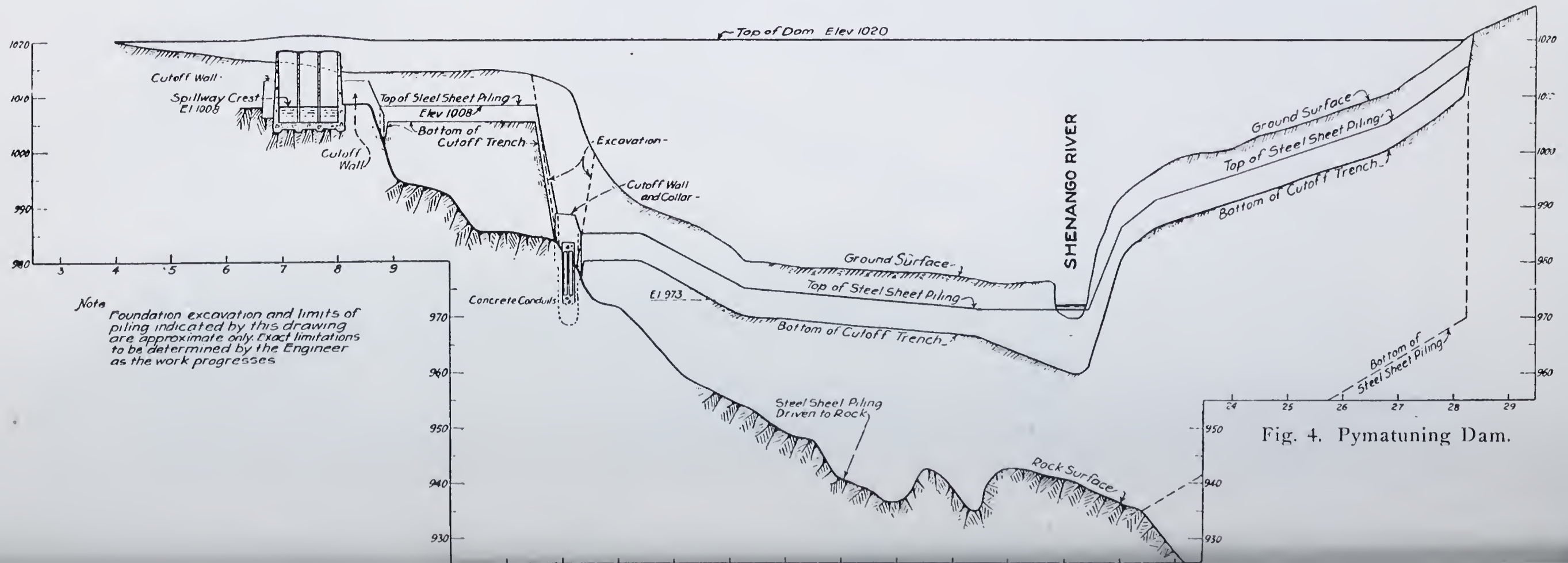


Fig. 4. Pymatuning Dam.

and in a drill hole put down this last summer near the left end of the dam, rock was found to be 138 feet below the surface of the ground. The Stearns plans provided for a rolled-earth embankment with a diversion channel and regulating structure in rock excavation near the right end. The main dam was to have an impervious earth core carried to rock across the valley bottom and to a depth of about 40 feet in the left hill, which was to be blanketed with clay above the dam to reduce seepage through this hill. The core was to be 10 feet wide on top with side slopes of 2½ vertical to 1 horizontal. Excavation for this core was to be carried to rock, and at the maximum section the base was over 50 feet wide. The sides of the excavation were to be 1 vertical to 2 and 1½ horizontal. These plans provided for a structure similar to that built for the city of Providence, R. I., for which Mr. Stearns was the consulting engineer.

The principal quantities involved in these plans were as follows:

Earth excavation, all classes	339,000	cubic yards
Rock excavation	27,600	cubic yards
Embankment from borrow	340,000	cubic yards
Portland cement	14,500	barrels
Concrete, all classes	10,000	cubic yards
Slope paving or riprap	12,100	cubic yards

An estimate of the cost of constructing the dam, based on these plans, was made by the engineers of the Board in September 1930, so that it might be included in the 1931-1933 budget request prepared in the latter part of September 1930. This estimate amounted to $1,490,000 for the complete dam and spillway, including engineering, inspection, contingencies, and extras. The unit prices used were based on costs then prevailing under contracts and bids for the construction of dams, and upon prices received from the State Highway Department for similar items of construction. Although the trend of prices was downward at the time, it was impossible to predict what they would be in the summer of 1931, which was the earliest date when construction could be started if an appropriation were made available. When it became certain that the Legislature of 1931 would make an appropriation for the construction of the dam, the plans prepared under the direction of Mr. Stearns in 1919 were reviewed, and revised plans prepared in accordance with present

practice and present standards of design under the direction of the Chief Engineer of the Water and Power Resources Board, and approved by Mr. Arthur E. Morgan, who became Consulting Engineer to the Commission after the death of Mr. Stearns. Fig. 3 shows the general plan, and Fig. 4 the cross-section and profile.

These revised plans provide for a rolled-earth embankment, 2400 feet long and 50 feet in maximum height, with a spillway founded on rock around the right end, a regulating structure consisting of a gate-house at the up-stream toe of the dam, and a reinforced concrete conduit with two tubes six feet by eight feet under the embankment and an approach channel on the up-stream side excavated mostly in earth. The width at the top will be 32 feet, and the slopes will vary from 1 on 2 to 1 on 3, with berms on both up-stream and down-stream slopes. The cut-off in the embankment will be an impervious earth core founded in a comparatively shallow trench, in which will be driven an interlocking sheet-steel piling cut-off to rock, or to a maximum depth of about 40 feet in the left hill. There will be a difference of 12 feet elevation between the flow-line and the top of the dam. The up-stream slope of the dam will be protected by riprap.

The principal quantities involved are:

Embankment	370,000	cubic yards
Excavation	180,000	cubic yards
Concrete	5,200	cubic yards
Cement	7,500	barrels
Paving and riprap	13,000	cubic yards
Sheet-steel piling	900	tons

An estimate of cost based upon these plans and the prices prevailing in June 1931, excluding the gate-house and engineering, was $733,000. Prices continued to fall, and just before the receipt of bids on September 1 we estimated the cost, exclusive of engineering and the gate-house, at $550,000.

Advertisements for bids were published on August 14, 18, and 24, 1931, and bids were opened on September 1, 1931. Thirty bids were received, the highest being about $734,000, the average about $520,000, and the lowest about $340,000. The lowest bidder was C. R. Cummins, Inc., of Cleveland, a subsidiary of Ulen and Company.

A summary of the difference between the low bid and the 1930 estimate of cost follows:

Economies in design	$ 550,000
Estimated cost of constructing gate-house and bridge from gate-house to dam, to be built later	50,000
Estimated cost of engineering administration, contingencies and extras	110,000
Estimated decrease in construction cost between September 1930 and August 1931	255,000
Cummins bid below average of 30 bids received	180,000
Cummins bid	340,000
1930 estimate for dam and spillway	$1,490,000

Two of the interesting provisions of the specifications are those relating to the residence of employees and to a minimum wage scale. The former provides that the contractor in employing workmen, both skilled and unskilled, shall so far as practicable give preference to citizens of Pennsylvania and Ohio, particularly those residing in the vicinity of the work. The minimum wage scale provision required by the Legislature in 1931 provides a minimum scale of wages to be paid skilled and unskilled labor under a penalty "of an amount equal to twice the difference between the minimum wage contained in said specifications and the wage actually paid to each such laborer or mechanic for each day during which he has been employed at a wage less than that prescribed in said specifications." The minimum wage scale specified is:

1. Operators of major power-driven machines and equipment such as power shovels, cranes and excavators. Minimum wage ..... 75 cents an hour

2. Artisans and mechanics of the building and construction trades. Minimum wage ..... 60 cents an hour

3. Operators of minor equipment such as trucks, tractors, power graders, compressors, drills, pumps, and road rollers. Minimum wage ..... 45 cents an hour

4. Skilled laborers using hand tools not power driven, requiring some training and skill, and artisan helpers. Minimum wage..... 40 cents an hour

5. Laborers, workers with hands or with hand tools, not requiring special training or skill. Minimum wage 35 cents an hour

ORGANIZATION OF FIELD FORCES

For the construction of the dam, a special field organization was created consisting of a resident engineer, a designer, a draftsman, a field engineer, inspectors, instrument men, and rodmen. The resident engineer is Mr. C. C. Chambers, who has had considerable experience in dam construction, having been division engineer in charge of the construction of the Huffman dam for the Miami Conservancy District, 1917-1922; resident engineer in charge of investigation, design and superintendence of the construction of an earth dam in West Virginia, 1923-1925, and resident engineer in charge of the construction of the Conklingville dam for the Hudson River Regulating District of Albany, New York, 1928-1930.

OFFICE BUILDING

A farmhouse on the property near the site of the dam has been remodeled at an expense of about $6000 to serve as a field office during the construction of the dam, and as an administration building and office for the maintenance and operation of the reservoir after its completion.

PROGRESS OF CONSTRUCTION

Work on the dam was begun on October 6, 1931, when Governor Pinchot, in the presence of a gathering of about 20,000 interested and enthusiastic residents of the valley, including many prominent citizens of Pennsylvania and Ohio, turned the first spadeful of earth. Since then progress upon the construction has been continuous and the contractor has, at this time, completed a major portion of the up-stream section of the embankment which will be used as a coffer-dam when the closure is made in the present river channel to divert the flow of the stream through the diversion channel and the conduits around the dam. The excavation for the entrance

and outlet channels has been completed and the conduits are about two-thirds completed. The contract calls for the diversion of the river by May 15, 1932, and for the completion of the entire work by May 31, 1933. It is hoped and expected that work upon the structure will be well enough advanced by the early spring of 1933 so that advantage may be taken of the wet season to begin storing water in the reservoir. The average number of mechanics and laborers employed by the contractor has been in the neighborhood of forty, and a large number of the laborers are residents of Pennsylvania.

The contract requires a certain rate of progress to be made per construction month, and at this rate the required progress to February 1 would amount to approximately $58,000, or 17 per cent. of the total cost of the work. The contractor, at this time, has not quite kept pace with this schedule, as the total amount of the estimate as of January 31 was about $32,000. This matter has been brought to the attention of the Cummins company and I have no reason to believe that the work will not be sufficiently well advanced by May 15 to permit diversion of the river, so that work upon the construction of the main embankment may be begun immediately after that date. Test sections of interlocking sheet-steel piling have been driven and pulled, and the contractor is preparing to drive the piling across the valley within the near future.

PENNSYLVANIA-OHIO PYMATUNING COMMISSION

Shortly after the appropriation for the construction of Pymatuning dam was made available, Governor Pinchot suggested to Governor White, of Ohio, the creation of a joint commission for the purpose of considering certain matters relating to the maintenance and operation of the Pymatuning project which might well be settled by an agreement between the two states. He suggested that such matters might, among other things, relate to questions affecting fishing and hunting; the use of the reservoir for boating and recreation; policing, sanitation, and restrictions concerning the use of the marginal lands; game and bird refuges, and kindred matters. Agreeable to this suggestion, Governor White appointed the Director of Highways, the Director of Public Works, the Chairman of the State Conservation Commission, and Mr. C. A. Bock, of Dayton, Ohio, as members of the Ohio Commission. Governor Pinchot appointed

Lewis E. Staley, Secretary of Forests and Waters, as Chairman of the Pennsylvania Commission. The other members of the Commission are Samuel S. Lewis, Secretary of Highways; Dr. Charles E. Reitell, Director of the Pennsylvania Council; Dr. Theodore B. Appel, Secretary of Health; Ross L. Leffler, President of the Board of Game Commissioners; O. M. Deibler, Commissioner of Fisheries, and the writer as a member of, and Secretary and Technical Adviser to, the Commission. The reservoir site has been examined by members of the Ohio and Pennsylvaina commissions and a joint meeting of the two bodies will be arranged at an early date.

DISCUSSION

W. L. R. Haines:* You speak of the dam being so constructed that it would be possible to raise it in the future. That would be, I take it, for the canal, in order to impound sufficient water taken from French Creek.

C. E. Ryder: Under the plan outlined in the report of Mr. Stearns, to which I have previously referred, it would be possible to bring water by canal from French Creek and store it in an enlarged reservoir, the enlargement being made by increasing the height of the dam 12 feet. That would bring the flow-line from an elevation of 1008 feet, as at present contemplated, to 1020 feet, and thus provide 82,000,000,000 gallons additional capacity. This stored French Creek water would be used to supply the summit level of the canal.

J. N. Chester:† Would that submerge Linesville, Pa.?

C. E. Ryder: That would not submerge Linesville. I think it would extend into the borough limits, but would not submerge the built-up portion of the town.

J. N. Chester: What is the mean minimum and what is the mean average of the stream at the dam site in cubic feet per second?

*Assistant Engineer, Pennsylvania Railroad, Pittsburgh.
†Senior Partner, J. N. Chester Engineers, Pittsburgh.

C. E. Ryder: I do not remember those figures. At our Jamestown gaging station the low flow in 1931 was about four second feet.

W. L. R. Haines: If I may volunteer the information, in 1918-1919 the mean discharge of the Shenango River at Turnerville was 157 second feet, and in 1919-1920 it was 132 second feet. How long do you estimate it will take for the reservoir to fill after the dam is in?

C. E. Ryder: We think that, if we can begin to fill the reservoir in the spring of next year, we can fill it completely during the following year. I do not believe the reservoir would fill in one year unless we had an unusually wet year. We have made studies to determine the fluctuations in the Pymatuning reservoir, assuming that it had been built and in operation over a period of 23 years, and assuming also that varying amounts of water were released from the reservoir to maintain certain different rates of flow at Sharon and other points in the Shenango valley. A flow of 400 second-feet can be maintained during the dry season of the year at Sharon with a usual draw down of the reservoir from the spillway elevation of 1008 feet to about 1002 or 1003 feet; frequently less than that. That figure of 1002 feet would be the maximum draw down over the period of 23 years with the exception of two years, 1923 and 1931. During those two exceptionally dry years the reservoir would have been drawn down to 996 feet, or a distance of 12 feet below the spillway crest.

W. L. R. Haines: There would be very little water behind the dam.

C. E. Ryder: By referring to the map, you will observe that the Pennsylvania Railroad crosses the proposed reservoir a short distance south of Linesville. We shall raise the railroad and adjoining highway and use the embankment as a secondary dam to maintain about 4000 acres of the reservoir at an approximately constant elevation of 1010 feet. This will be used as a migratory bird and game sanctuary. Nothing definite has been decided with reference to the operation of the remaining portion of the reservoir below the Pennsylvania Railroad. It seems to me it will be a matter of development as we learn

by experience how we may best meet the needs for domestic and industrial water-supply and sanitation in the Shenango and Beaver valleys and at the same time interfere as little as possible with the use of the reservoir for recreational and other purposes. It must be kept in mind that the primary purpose of the reservoir is to regulate the flow in the Shenango and Beaver rivers. We realize that there may possibly be a dispute between those people interested in having a continuous largely augmented supply of water in the river below the dam, and those other people, probably a larger number, interested in recreation and in maintaining the reservoir at a constant elevation. The maximum draw down during the average year will be comparatively small and it will occur after the summer season. We therefore believe it will be possible to operate the reservoir so as to serve both purposes satisfactorily.

P. W. Price:* Did you say there would be a spillway as well as these regulating conduits?

C. E. Ryder: There will be a spillway in addition to the two conduits. The spillway will be approximately 115 feet long with a depth of 12 feet. We estimate that the 1913 flood, the greatest recorded flood in the valley, would have raised the reservoir so that about two feet of water would have gone over the spillway. The factor of safety is greater than in any other dam of which I know.

E. K. Morse:† The Pymatuning dam project is primarily intended as a storage reservoir for commercial purposes during periods of dry fall months, and during the months of September, October and November is subject to drainage which will expose unsightly shore lines. The tourist season and summer cottage life end about the time the schools open in September or about the time when the reservoir is being drained for domestic purposes. It is believed that when travelers see this beautiful lake and enjoy the sports of this state-owned and state-controlled area of waters and parks, public opinion will demand that the waters of the Pymatuning be kept at an elevation of 1008 feet, which is a full reservoir.

*Assistant Construction Engineer, Bureau of Bridges of Allegheny County, Pittsburgh.

†Engineer, Pittsburgh.

Conneaut Lake is only a few miles east of Pymatuning Swamp and is 62 feet higher than the flow-line of the Pymatuning reservoir.

The estimated run-off of Conneaut Lake is about 1,000,000,000 cubic feet, but the lake provides only a small storage capacity. Adequate storage could be obtained by building a dam near the mouth of Cussewago Creek at Meadville, Pa. At least 3,000,000 cubic feet could thus be obtained and drained by gravity into Conneaut Lake by driving a small tunnel about the size of a coal-bank entry under the high ridge separating the watershed of Conneaut Lake from that of Cussewago Creek. These two watersheds combined can be designed to maintain a full lake at all times in the Pymatuning reservoir.

This diversion of the waters from French Creek will not be missed in the Allegheny River and will be wholly within the state of Pennsylvania.

J. N. Chester: What has been the average cost per acre of clearing the land?

C. E. Ryder: We have not made that calculation. The clearing began only a short time ago and the force has been gradually accumulating from a crew of 30 at the beginning up to a little over 400. The figures that I have received were furnished by Mr. Ferris yesterday and include, I think, only the cost for hiring the men. They do not include the cost of equipment, which, at the beginning of the job, naturally would be a very large percentage of the total cost. We have purchased axes, saws, sledges, peaveys, trucks, tractors, and all necessary supplies and equipment which will be needed for a force of possibly a thousand men. We have not attempted at this time to estimate the cost of clearing per acre.

J. N. Chester: To what extent are you removing stumps?

C. E. Ryder: I am glad you brought that up, as I did not mention it in my paper. It was our original intention to remove stumps in the portion of the reservoir between the dam and the Pennsylvania Railroad between elevations 1002 and 1010, the normal range of the draw down. Since then a question has been raised as to the necessity for, or advantage of, undertaking the removal of stumps between

those elevations throughout the entire area below the Pennsylvania Railroad.

The Board at its last meeting decided to make a thorough and careful study of this matter and appointed a committee, consisting of O. M. Deibler, Commissioner of Fisheries; E. K. Morse, engineer member of the Board, and W. S. Stevenson, Chief Engineer of the State Department of Health. The Committee will submit a report at the next meeting of the Board, to be held within the next two weeks.

A. C. Ackenheil:* Will you describe the methods of construction of the embankments and other phases of the work now going on, a little more in detail?

C. E. Ryder: There has been very little embankment construction up to this time. The only earthen portion of the dam that has been built is that near the up-stream toe, which will be used as a dike to divert the water through the conduits beginning next May. The material for this portion of the embankment was obtained largely from material excavated for the construction of the conduits, also from material taken from the excavations for the spillway and a small amount of material taken from borrow. This material, as I remember the specifications, was placed in six-inch layers and rolled with a 12-ton roller. Bulldozers, trucks, tractors, and other equipment help to pack down the embankment. The contractor will be unable to work on the main portion of the embankment until the river has been diverted on May 15. A portion of the material will be obtained from excavation for the diversion channels, cut-off, conduits, and spillway, but a larger part will be taken from borrow pits near the site. The contract price for material obtained from borrow is 24½ cents per cubic yard. The contract provides also for spreading a clay blanket over the valley bottom above the dam, and particularly over the hillside on the east side, which is not as tight as the material on the west side.

W. M. Austin:† I want to ask Mr. Ryder about the removal of the stumps. Do they cut off the large brace roots of the trees and

*Engineer, J. F. Casey Co., Pittsburgh.

†Circuit Breaker Engineering Department, Westinghouse Electric and Mfg. Co., East Pittsburgh, Pa.

then pull the tree over with a cable, thereby breaking off the tap-root and smaller roots; or do they cut the trees first and then pull or blast out the stumps?

C. E. Ryder: There will be very little blasting done in the removal of stumps. In the case of very large trees, holes will be bored in the tops of the stumps and dynamite used to split them and loosen the roots, after which the sections will be pulled with a tractor and winch. In the area between elevations 1002 and 1010 feet, trees having a diameter in excess of four inches will be cut six or eight feet above the ground, and with this leverage all except the largest stumps may be pulled without difficulty.

W. L. R. Haines: Mention was made of the possibility of diverting the water of French Creek across the divide to maintain the uniform elevation of 1008 feet. I know that in the past some question has been raised as to the legality of such diversion. Do you know whether the legal department of the state has ever rendered an opinion as to whether the French Creek waters could be diverted?

C. E. Ryder: I do not know that that question has been raised or an opinion requested from the Attorney General. Certainly the Water and Power Resources Board has not asked for it and I have not heard of an opinion having been rendered in connection with the suggested diversion for canal purposes.

A. C. Ackenheil: What influenced the Board to award the contract for rolled fill rather than hydraulic?

C. E. Ryder: Either type of construction would have been acceptable to the Water and Power Resources Board, and both were provided for in the plans and specifications. The award was made to C. R. Cummins, Inc., of Cleveland, the lowest of 30 bidders, under the proposal to build the dam by means of a rolled embankment. As a matter of fact there was very little difference between that bid and the bid of the Arundel Company of Baltimore, which submitted a proposal to build the dam by the semi-hydraulic method. The contract was awarded to the lowest bidder.

MORRIS KNOWLES:* We owe a debt of gratitude to Mr. Ryder for his comprehensive, unique and interesting paper. Two thoughts interested me.

Engineers too often forget the human element. Reference in this case is to the author's very complete story by which he explained how it was arranged to do certain of the work by day labor, the selection of the people, the housing, sanitation, protection of health and the general care of the men who are to work, and the fact that there has been so little dissatisfaction between the workmen and the administration. I am familiar with the work done in New York state, with water-supply construction for New York City, for the Boston Metropolitan district, the Birmingham district, and a number of others of like magnitude, and I know of no other project in which such care has been paid to the human element, in the maintenance of the worker's interest in his work and in the care for the lives of employees, as the author has given to us in his interesting description this evening. We engineers deal so much with materials and implements that we are apt to forget that we have also to deal with human beings.

The other thought is that this project will be the first demonstration in Pennsylvania of the theory propounded by the Flood Commission of Pittsburgh in its report in 1911, that you could build reservoirs for dual purposes—to provide storage that will regulate streams, so the floods will be less in height, and also to provide for increased flow at the time of low water. The author has carefully shown that it is possible so to do.

J. N. CHESTER: My interest in this comes first from some property interests at Jamestown, where we are hoping the water-supply will be better, so we have been interested all along in the progress of the work; and my interest was intensified by the fact that five years ago we completed a similar project near Shreveport, La., though our completed capacity did not exceed 20,000,000,000 gallons.

C. E. RYDER: The Pymatuning reservoir storage will amount to 64,000,000,000 gallons.

J. N. CHESTER: Our spillway was not as long, but Nature did more for us. Our total cost was $10 a million gallons, and it is the

*President, Morris Knowles, Inc., Pittsburgh.

lowest other than yours that I have ever seen. One reason for our low cost was that the Kansas City Southern Railroad crossed just where we selected the dam site and we obtained permission to utilize the railroad grade as a dam, we agreeing to put a small clay fill made as nearly impervious as possible and use stone riprap. The spillway was built where a trestle had been maintained as a bridge. This had been renewed three times and the bents placed at different points, so by sawing off those piles we got a complete foundation for our spillway. We supplemented it by sheet-steel piling down to impervious fill, 10 feet below the floor level of the lake.

Our average depth was about 10 feet. About one-third of it was timbered and, as at Pymatuning, when the land owners found out that the land was to be taken they cleared off all the big trees. It was cypress lumber and was very valuable, but there was none there of any account when we got to it. All stumps down to eight inches had to be removed. Up to eight inches could be cut off and left, but if less than two inches had to be cut off at the ground level. I am sorry I can not commend the preparation there as Mr. Knowles has commended Mr. Ryder. However, I believe our sickness and accidents were as low down there as they were here with practically no preparation. The labor was all southern negro and what they had to drink was characterized by the health officer of Shreveport as what nothing but negroes and alligators could drink and live; still there was little or no sickness. The work, however, was in charge of the State Board of Health. I think the clearing of our reservoir cost about $150,000.

The thing that seemed to concern the Health Department most was that the untimbered area was covered by a most luxuriant growth of cocklebur. We burned off what we could and flooded the rest. The first year there was no rain, but the second year was a very wet one. We had the highest flow of water over the spillway in August and September that has ever passed over that except when it flows up. When the Red River gets above 25 feet we have an upflow over the spillway and it once got to 39 feet. The river does not play that trick more than one year out of seven. That country is not a good place to store water in shallow reservoirs, so the capacity of the reservoir was created largely to obtain depth to preserve the purity of the water. With the reservoir all washed out, we have had

no complaints regarding the character of the water. We had been using Red River water where the gypsum content would run 600 parts to the million. This supply averages about 32. So in a country where soft water was unknown, the water-supply assured by this reservoir is one of the finest supplies I have ever encountered.

L. P. Blum:* What are the characteristics as to hardness of the impounded water?

C. E. Ryder: I can not say as to that from actual analysis, as questions relating to the quality of the water come under the jurisdiction of the Sanitary Water Board. However, the upper Shenango River drains a glacial area and I should judge that the water would be soft.

E. K. Morse: I do not wish to cut this discussion short, but as lantern slides are planned to follow this discussion I feel that we should allow Mr. Ryder to proceed with his subject.

George M. Lehman:† The outstanding importance of the Pymatuning reservoir to the Shenango and Beaver valleys is quite evident. In fact, the direct and indirect benefits will be so vast and numerous that it is difficult to measure the extent properly.

When considering the present purposes of the reservoir, and finally the proposed canal, the writer of this discussion does not know of any project of similar nature in this country. It is, of course, widely known that reservoirs are in successful use for water-supply and power and also for stream regulation. This project has been thoroughly studied and worked out by the author of the paper and his able associates and, while unique, as said by one of those present, there is every assurance that its broad scope will work out successfully, perhaps beyond what is now expected. The project illustrates what is possible in other localities in this region, and how water under proper control may be put to use, tremendous waste prevented, and loss to business and distress to the home greatly avoided.

In this instance the lack of adequate water for industries during the summer and fall months, and the frequent high river stages and

*Blum, Weldin & Co., Pittsburgh.

†Chief Engineer, Lake Erie and Ohio River Canal Board, Pittsburgh.

periodical floods are costly and serious, but in addition to these direct troubles is the almost constant flood menace and the disturbance of mind during a considerable part of the year. The menace tends to keep down property values, retard business, and in many cases discourage improvements. Even near-by areas not in direct contact are affected.

The value of such projects is not sufficiently realized and the interest taken in their promotion is surprisingly small, even by those eventually to be benefited. There should be a prompt awakening. While little time remained after reading of the paper, it is unfortunate that the economics of the project did not receive real attention.

It is not only a matter of industrial upbuilding, but transportation would quite naturally be greatly benefited. A considerable portion of business increase would of course be enjoyed by the railroads. The regulation of the river flow as planned will permit navigation on the Shenango in case the stream is improved for that purpose.

It was reported by the Water Supply Commission, which has been replaced by the Water and Power Resources Board, that, had the reservoir been in operation at the time of the 1913 flood, at Sharon the flood reduction would have amounted to about four feet and on the Shenango and Beaver rivers 80 per cent. of the sustained damage would have been prevented. The estimated damage amounted to about $2,100,000.

Mr. Ryder referred briefly to the proposed canal and the French Creek feeder line and stated that for this project the dam of the reservoir at the proper time is to be increased in height 12 feet above the original top of the spillway, which will permit a total storage capacity of over 18,500,000,000 cubic feet, of which somewhat over 10,000,000,000 will be available for the canal. The elevation of the water surface would be 1020 feet, the area covered about 38½ square miles, and the length of shore line 80 miles. About 20 per cent. of this reservoir would be in Ohio. About 14 islands will be formed, having an aggregate area of over 200 acres. The location of the dam as selected in the work of the 1914 Canal Board was about 1.8 miles above the dam now being constructed.

It should be understood that since the canal survey of 1895 this reservoir site has formed a definite part of the canal plan. The first topographic survey and contour map of the swamp were made at that

time, and the adopted route of the canal and sources of water-supply are now much the same as proposed in that year. However, since then, improvements have been made in places. The writer has been connected with the project since 1895. In 1910 the Water Supply Commission was urged to give actual consideration to the use of Pymatuning Swamp for the canal, and this was acted upon favorably. Investigations and complete field surveys were made by a canal company in 1905. The first Canal Board of the state, in 1914-1915, made very extensive studies, field surveys, and estimates of cost. This work, which included detailed maps and plans, has been much used by the Corps of Engineers of the United States Army in the study of the proposed canal.

Under the present Canal Board the whole project is receiving most thorough study not only as to engineering features, but with regard to economics, under modern conditions and requirements. It is the desire of this Board to have new and authentic opinions with regard to the project by those fully experienced in waterway engineering and transportation in general. The report of those engaged for this work is about completed. The proposed route is shown in Fig. 5.

It may be well to explain that in addition to the feeder line from French Creek to Pymatuning reservoir, 20 miles in length, the canal plan necessarily includes one from the reservoir to the canal. This feeder, including a small reservoir on the line, will have a length of about 30 miles. It will have a capacity of about 700 second feet, and will leave the reservoir from the northwestern side and enter the canal at the north end of the summit, which is in Ohio and by air line nearly 15 miles from the Pennsylvania-Ohio boundary. It is likely well known that the proposed canal route begins at the mouth of the Beaver River and by canalization follows the Beaver and Mahoning rivers to Niles, Ohio, 50 miles, and thence directly overland 51.4 miles, joining Lake Erie at or near Ashtabula. The total length is 101½ miles. The summit level, over 27 miles in length, will have an elevation of 900 feet, and on this level it is planned to have a lake nearly nine miles in length, formed by a comparatively short dam constructed at the south end.

The proposed minimum bottom width of channel will not be less than 140 feet at a 12-foot depth. With double locks the actual aver-

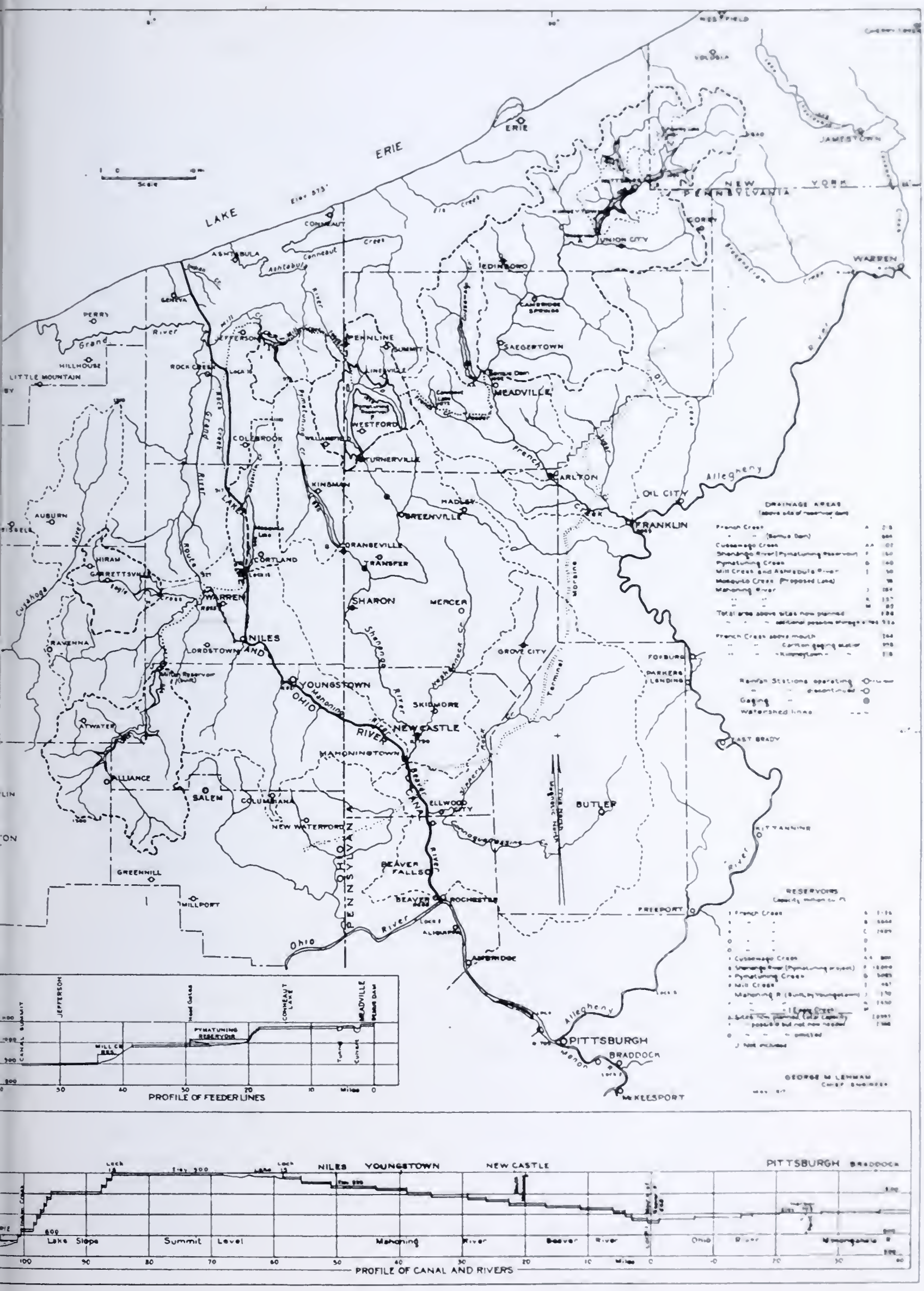


Fig. 5. Proposed Lake Erie and Ohio River Canal.

age annual tonnage movement, after attention is given to speeds, loads and handling, is estimated to approach 40,000,000 tons per season.

This route has been studied by the Corps of Engineers of the United States Army, and called by them Route 1. Their engineering report pronounced the project entirely feasible in every respect.

In the discussion of Mr. Ryder's paper the question was raised by Mr. Haines as to whether the town of Linesville would be materially encroached upon by the canal 1020-foot elevation of the reservoir, and it was explained that this would not occur. At this place the water remains within the banks of Linesville Creek. As to the legality of taking water from French Creek there appears to be no question about this when considering the purpose. The Pymatuning reservoir will be used for the through canal to Lake Erie. It is not required for navigation on the Mahoning River.

Reference was made by Mr. Morse to Conneaut Lake as a source of aid toward maintaining the 1008-foot level of Pymatuning reservoir; the intent being to store an additional two feet on the surface of that lake. The small supply from this lake with an area of only about 1.4 square miles, even if available for a considerable part of the season, would likely make very little impression upon the large reservoir. The water would have to be carried about seven miles.

The suggested scheme of taking water from a reservoir built on Cussewago Creek, which might have a capacity of about 4,000,000,000 cubic feet, was also mentioned. The writer, in 1909, in studies made for the Flood Commission of Pittsburgh, found that the feasible storage of a site on that stream would not exceed about 800,000,000 cubic feet.

It may be interesting to mention the fact that storage by three reservoirs in the upper waters of French Creek is feasible to the extent of at least 6,000,000,000 cubic feet. This water, regulated, would drain down the creek channel to the head of the proposed feeder close above Meadville. One of these reservoirs (A) was included in the work of the Flood Commission of Pittsburgh. When selecting this site the writer had the canal project also in mind. These reservoirs would be of great service for flood and stream regulation and would meet other demands, if found necessary, at the Pymatuning reservoir. The smaller one on Cussewago Creek, if desired, could be linked with the head of the canal feeder above Meadville,

and the whole operation of these reservoirs would relieve that city and other points from practically all flood damage. A very important thing is that the stored water of the higher stages and floods, as in other cases, would be put to economic use. The late Mr. Stearns, who was a prominent authority on water-supply, carefully examined the canal water-supply problems with regard to joint use of the Pymatuning reservoir and in this connection made certain recommendations. His report was quite favorable.

It evidently will be realized that the proposed canal, which of course is of national importance, will also be of vast service in many respects to a very large local area. The small canal map printed in 1917, and reproduced on a reduced scale in Fig. 5, illustrates this. The features shown on this map relating to water-supply are intended to indicate the possibilities at hand. It does not mean that all those outlined are required. It may be observed that the map indicates topography of very favorable nature for working out the entire plan.

BOARD OF DIRECTION MEETING

April 19, 1932

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor D of the William Penn Hotel, Tuesday, April 19, at 12:00 o'clock, Vice President A. S. Davison presiding in the absence of President F. R. Phillips, Messrs. W. L. Affelder, W. H. Buente, Joseph Bryan, H. N. Eavenson, J. F. Laboon, G. F. Osler, T. E. Purcell, L. J. Riegler, E. C. Stone, G. E. Stoltz, J. F. Robinson and J. P. Warner being present, Messrs. Norman Allderdice, L. C. Edgar, F. F. Schauer, Lauson Stone and A. Stucki being absent.

The minutes of the last regular meeting, held March 15, were approved without reading.

Applications from the following gentlemen, having been published to the Society pursuant to the action of the Board, were elected to membership:

MEMBERS

Berry, William Jerome — Whartenby, C. Alfred

ASSOCIATE MEMBER

Wyre, Donald H.

JUNIOR

Blue, Albert W.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Jens, Walter Galt — Wheeler, Harold R.

ASSOCIATE

Lessig, J. Frank

An application for reinstatement was received from J. V. Breisky, and after discussion it was moved and carried that he be reinstated to membership in the Society.

Letters of resignation were received from the following, and after discussion it was moved and carried that they be accepted with regret: A. J. Acker, H. R. Burgess, E. H. Coxe, Jr., L. P. Kennedy, C. A. Sipe and E. J. Uhl.

The following deaths were reported:

W. R. Webster, 2333 North Seventeenth Street, Philadelphia, Pa. Joined the Society December, 1927. Died April 11, 1932.

J. Hammond Smith, 6363 Douglass Street, Pittsburgh, Pa. Joined the Society November, 1903. Died April 13, 1932.

The report of the Secretary, showing the condition of finances at the close of business March 31, having been audited by the Finance Committee, was approved. In connection with the Secretary's report, the Finance Committee reported that receipts decreased about $2,000 during the month of March. This is probably due to the Society encouraging the members to pay their dues quarterly, rather than in advance. Almost the same number of members have paid dues as last year, but about 200 have taken advantage of making quarterly payments.

Mr. Davison, Chairman of the Entertainment Committee, reported a most successful Ladies' Night Party, with an attendance of 342.

The Meetings and Papers Committee reported that plans were under way for meetings next year and it has been unanimously decided, in view of existing conditions, to discontinue the lecture course, and to substitute meetings at which speakers of national prominence will present timely subjects of general interest.

The Secretary presented a letter, dated March 28, 1932, from the Pennsylvania State College, asking us to appoint delegates in accordance with our usual custom for the election of Trustees, to be held in June. It was regularly moved and carried that this be referred to Mr. Affelder, with the request that he appoint such delegates.

The Secretary presented two bills forwarded to the Society by the American Engineering Council—No. S. 4040, having to do with the construction and maintenance of a toll bridge across the Monongahela River at Fayette City, Pa., and Bill S. J. Res. 120, authorizing and directing the Interstate Commerce Commission and the United States Shipping Board to make a joint investigation into the practicability of equalizing rail rates and ocean rates on export and import freight traffic. After discussion, it was regularly moved and carried that these bills be tabled.

Mr. Davison presented the following letter, dated April 19, from C. A. Carpenter, a member of the Society:

Engineers' Society of Western Pennsylvania,
William Penn Hotel, Pittsburgh, Pa.

GENTLEMEN:

As a result of the present depression, several social theories inimical to engineering are being given wide publicity. It, therefore, seems to me that engineering organizations should do everything in their power to develop sound views as a matter of protection to the profession as a whole.

People of considerable prominence in our national life are advocating the restraint of new inventions in order to prevent so-called technological unemployment. Others advocate putting the burden of business revival on large industries by an intensive campaign of modernization. The reduction of working hours is being claimed as the cure.

I would suggest that the Engineers' Society of Western Pennsylvania organize a committee to study the relation of the engineer to present social theories so that our Society may take a stand in defense of the technical development of ths country and of the continued value of the services of engineers to society.

Respectfully yours,

CHAS. A. CARPENTER.

After discussion, it was regularly moved and carried that Mr. Carpenter be appointed Chairman of a Special Committee, the members of which are to be appointed by him for the purpose of considering the problem mentioned in his letter and that this committee report its findings to the Board at a future meeting.

Mr. Davison, Chairman of the Medal Award Committee, reported that a meeting of the Committee had been held Tuesday, April 19, and after going over all of the papers published in the PROCEEDINGS during the year 1931, it was unanimously recommended that the gold medal be awarded to J. W. Rickey, Chief Hydraulic Engineer, Aluminum Company of America, Oliver Building, Pittsburgh, for his paper on "Chute à Caron Hydro-Electric Development," published in the January 1931 PROCEEDINGS and presented at the November 12, 1930, meeting of the Civil Section. After discussion, it

was regularly moved and carried that the recommendation of the committee be approved.

Mr. Davison presented a report of the Engineers' Relief Committee, stating that up to this time about 195 cases have been handled by the committee, 41 of which are receiving financial aid, and all of them have been given some type of work, except four. The committee is at present disbursing about $600 per week, and its finances will only last for about three more weeks at this rate. However, the Finance Committee is planning a drive for additional funds.

The meeting adjourned at 2:15 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION MEETING

May 17, 1932

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Crystal Parlor of the William Penn Hotel, Tuesday, May 17, at 12:00 o'clock, Vice President Davison presiding in the absence of President F. R. Phillips, Messrs. L. C. Edgar, Paul Caldwell, C. W. Daubert, G. F. Osler, F. F. Schauer, G. E. Stoltz and J. P. Warner being present, Messrs. W. L. Affelder, Norman Allderdice, Joseph Bryan, H. N. Eavenson, J. B. Frease, J. F. Laboon, T E. Purcell, L. J. Riegler, J. F. Robinson and A. Stucki being absent.

The minutes of the last regular meeting, held April 19, were approved without reading.

Applications from the following gentlemen, having been published to the Society pursuant to the action of the Board, were elected to membership:

MEMBERS

Jens, Walter Galt — Wheeler, Harold R.

ASSOCIATE

Lessig, J. Frank

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Olken, Hyman — Thorsten, Thorleif

ASSOCIATE

Johnston, Carl T.

An application for transfer to a higher grade was received from Dan Evans Tatom, and after discussion it was moved and carried that he be transferred to full grade of membership.

Letters of resignation were received from R. W. Higgins and J. C. Hoar, and after discussion it was moved and carried that they be accepted with regret.

The following death was reported: Joseph A. Kelly, 5800 Wilkins Avenue, Pittsburgh, Pa.

The report of the Secretary, showing the condition of finances at the close of business April 30, having been audited by the Finance Committee, was approved.

The Secretary presented a letter from the International Association of Bridge and Structural Engineering, requesting our Society to appoint an

official delegate to Congress, which will meet in Paris this year. In view of the fact that we have no members residing in France at this time, the Secretary was instructed to acknowledge the letter, stating that the Society unfortunately would not be in position to be represened this year.

The Secretary presented a letter from H. M. Lawrence, Mining Engineer, American Standards Association, New York, requesting this Society to appoint a representative on Committee of the American Standards Association to develop standard specifications for clean bituminous coal. The letter suggested the appointment of J. B. Morrow, Preparation Manager of the Pittsburgh Coal Company, and after discussion it was regularly moved and carried that Mr. Morrow be appointed representative of this Society on the above-mentioned committee.

The Secretary presented a letter from the American Engineering Council regarding the creation of a National Department of Public Works. After discussion, it was regularly moved and carried that this matter be tabled.

The Secretary read a letter from Frank Vittor, Pittsburgh, stating the Roosevelt Civic Legion, in co-operation with a committee, is preparing to erect a statue of George Washington as the young surveyor, to be placed on the top of Mount Washington. All labor and materials are being supplied gratis and the committee requests the Engineers' Society to appoint an engineer to take charge of the preparation of plans for the steel erection and structural features. After discussion, it was regularly moved and carried that this matter be left in the hands of the Secretary, with the request that he secure, if possible, the co-operation of some member who is either a consulting engineer or a steel company engineer, for the purpose of assisting in this work.

The meeting adjourned at 1:15 P. M.

K. F. Treschow, *Secretary.*

PROBLEMS IN STEAM-TURBINE DESIGN*

By C. Richard Soderberg†

INTRODUCTION

The outward progress of steam-turbine development during the past ten years has been very remarkable in several respects. The heat consumption has been decreased by the use of higher operating temperatures and pressures, and by methods of regenerative heating; the turbine efficiency has been increased by refinements in the design of the steam path, and the maximum size of the individual units has been very materially increased. These advances have been paralleled by improvements in reliability and by an equally remarkable reduction in weight and space requirements.

The engineering literature of recent years has seen several outstanding papers[1-9]‡ in which the story of this progress is admirably presented, particularly with regard to the merits of the various types and arrangements of turbines. The present paper is intended as a brief discussion of certain of the most important fundamental problems of mechanical engineering involved in this development, rather than a discussion of details of design.

The paper is not intended to give an exhaustive discussion of all important turbine problems. Certain problems have been given special emphasis here because they have happened to figure prominently in the author's recent activity. Others, such as the problem of control, have been left out on account of lack of space for a worthwhile treatment. The statements concerning methods and designs in use refer to the practice of the Westinghouse Electric and Manufacturing Company, and may not always apply elsewhere.

THE PROBLEM OF PERFORMANCE, UNIT CAPACITY, AND EFFICIENCY

DEVELOPMENT OF HIGHER PRESSURES AND TEMPERATURES

The incentive of high operating pressures and temperatures is easily understandable in view of the possibilities for improvement in station performance. The scope of this problem extends beyond the

*Presented April 5, 1932. Received for publication May 4, 1932.

†Manager Turbine Apparatus Division, Westinghouse Electric and Mfg. Co., South Philadelphia, Pa.

‡See references at end of paper.

turbine proper and it is only in a restricted sense that it can be referred to as a turbine problem.

The problem is affected in a fundamental way when the practicability of reheat is admitted. There is, then, no definite limit to the operating pressures unless the temperature is carried beyond certain limits. It is difficult to draw definite conclusions with regard to the practicability of reheat, but there seems to be discernible a trend away from this complication in plant lay-out and initial expense. To the turbine builder as such, reheating naturally offers a somewhat simplified problem, since excessively high operating temperatures are generally not used in connection with reheating.

When reheating is not employed, the problem enters a stage in which the turbine builder is vitally concerned. The moisture content of the steam in the exhaust to the condenser is now the limiting feature, requiring for each inlet pressure and each cycle of regenerative feed heating a certain minimum inlet temperature. Fig. 1 and 2 show the relation between inlet pressure, inlet temperature, and moisture

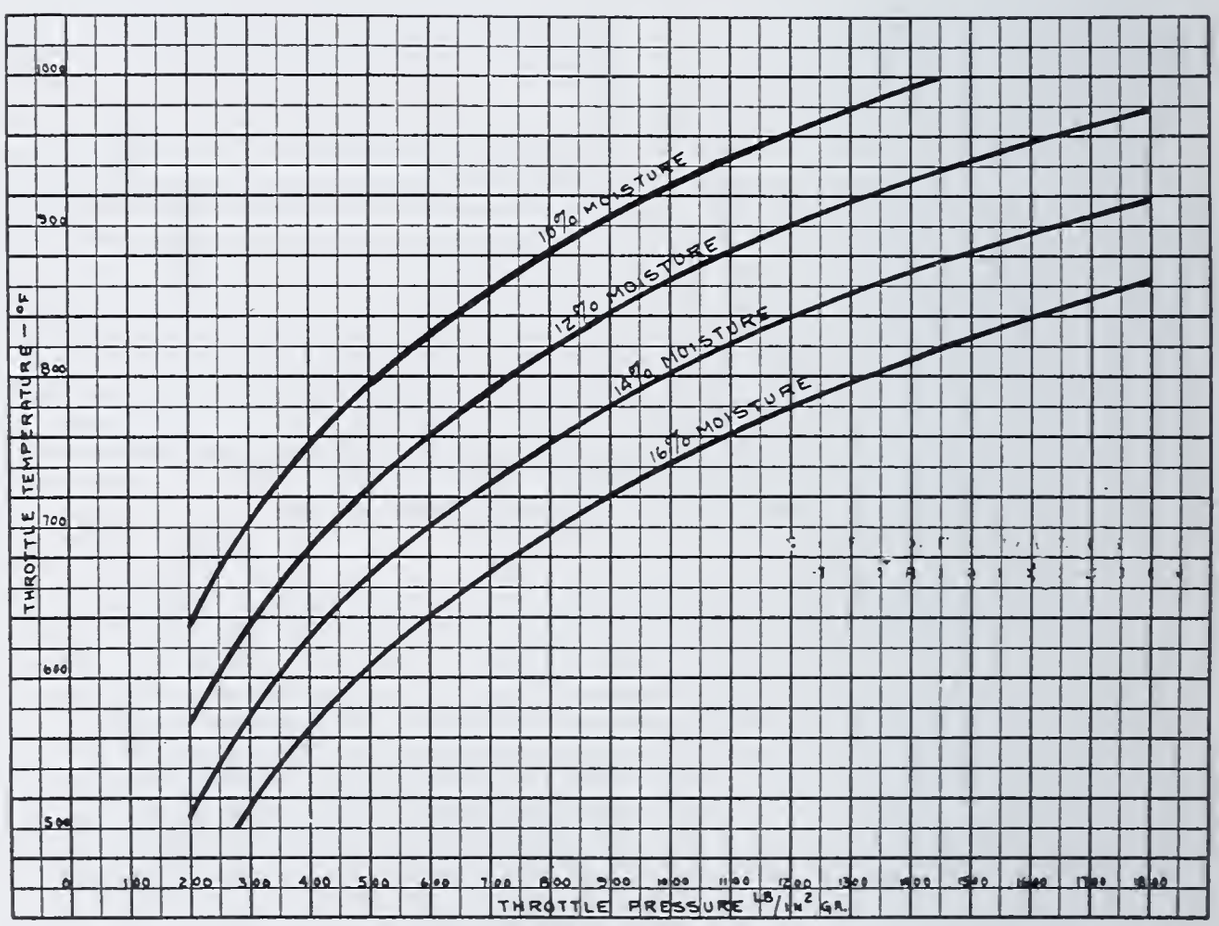


Fig. 1. Moisture Content in Exhaust with 29-Inch Vacuum and 80 Per Cent. Cycle Efficiency.

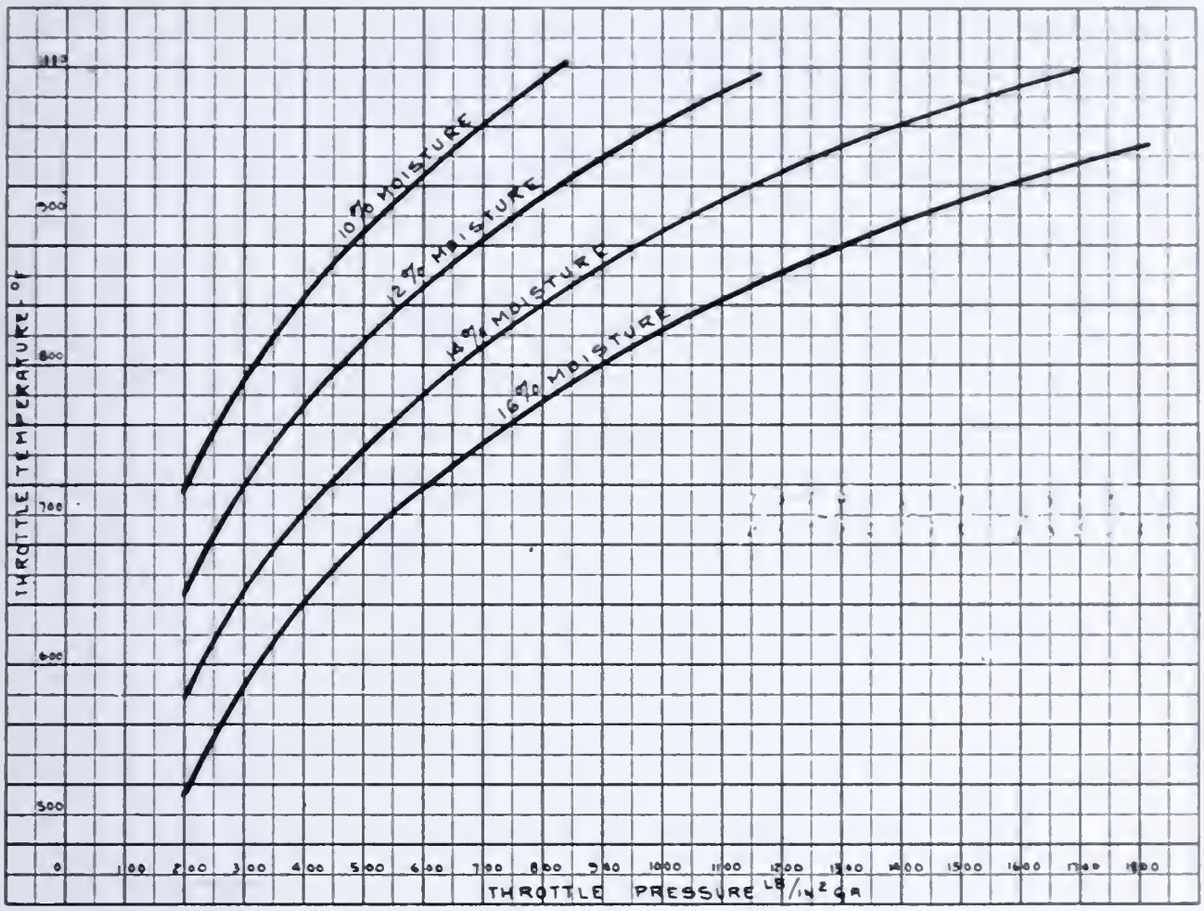


Fig. 2. Moisture Content in Exhaust with 29-Inch Vacuum and 85 Per Cent. Cycle Efficiency.

in the exhaust for typical turbines of modern design for central-station application. The pace is now set by the turbine builder (and the manufacturer of boilers and superheaters) through his ability to produce a reliable turbine for as high an inlet temperature as possible.

The present period of the development is an important one in this connection. An inlet temperature of 825 degrees F. may now be considered as established and practicable without material increase of maintenance. Fig. 2 indicates that, with 12 per cent. moisture in the exhaust, which is considered the limiting value for the high peripheral speeds now employed, the inlet pressure can not materially exceed 1200 pounds per square inch even assuming that an inlet temperature of 1000 degrees F. were practicable. Regardless of the desire to increase this pressure, there will undoubtedly be a tendency to raise the inlet temperature. The ultimate limit in operating temperature must be associated with the type of turbine involved. Large single-cylinder machines are inherently more sensitive to thermal distortions, and a very material increase of operating temperatures beyond 825 degrees

F. is not likely without fundamental changes in the details of the design for such machines. In the case of small, high-pressure cylinders of tandem-compound or cross-compound units, it is not improbable that 1000 degrees F. may ultimately become a practical operating temperature.

TREND TOWARDS LARGE SIZE OF INDUSTRIAL UNITS

The maximum output of a condensing turbine is determined chiefly by the last row of blading. The progress towards large size of individual units has thus been marked by a gradual enlargement of the last annulus. The first impetus was given in the development of the twisted and tapered blade whereby the ratio of blade length to mean diameter could be increased to the present values of 0.3 and more. This ratio being established, the discharge area was increased by increasing the tip speed to the present value in excess of 75,000 feet per minute. This necessitated extensive metallurgical developments to obtain blade materials that would stand the stresses imposed, and it brought about an accentuation of the erosion problem. These aspects will be discussed in a later part of the paper. By reason of these developments it is now possible to build single-cylinder condensing units in sizes approaching 100,000 kilowatts for operation at 1800 r.p.m. and 15,000 kilowatts at 3600 r.p.m. A 75,000-kilowatt machine is installed in the Kearny station of the Public Service Company of New Jersey. The same low-pressure ends used in multicylinder machines of the tandem or cross-compound type will give unit capacities of twice the above values. Two-cylinder, single-shaft turbine generators of 200,000 kilowatts for 1800 r.p.m. and 35,000 kilowatts or more for 3600 r.p.m. may thus be regarded as fully practicable at the present time.

IMPROVEMENT OF TURBINE EFFICIENCY

The improvement in efficiency ratio has been more outstanding for the smaller sizes of turbines, but for even the very largest machines the improvement is notable. The improvement has been obtained principally through (1) reduction of safe operating clearances in the high-pressure blading. The axial clearance type of reaction blading introduced originally by Parsons is perhaps the most important step in this connection; (2) improvements in the form of path of the blade to eliminate eddies; (3) improvements in the shape

and arrangement of the individual blades and nozzles; (4) reduction in the losses incidental to the moisture in the low-pressure end of the turbine.

The last groups of problems form the incentive for the large amount of research in hydrodynamics and thermodynamics which is carried out by the manufacturers of large turbines. The essential aspects of the designs rest on the same fundamentals as a number of years ago, but surprisingly great improvements have been obtained by elaborations in detail, however, and the work of this nature now in progress will carry the development still further. The improvement in efficiency ratio will undoubtedly continue for several years.

THE GENERAL PROBLEM OF MECHANICAL STRENGTH

GENERAL CONSIDERATIONS

In the steam-turbine the problem of strength is presented in a more complete form than in most other rotating apparatus. The applications of stress involve all variations of importance, and the materials encountered cover virtually the entire range of those known to mechanical engineering. The designer of steam-turbines, more than most other engineers, is constantly confronted with new and perplexing problems of strength.

The general problem of strength involves two aspects. Primarily, the problem consists in evaluating the danger of failure under the circumstances existing in the machine, or machine detail, under consideration. In order to obtain this evaluation, it is necessary to have access to two classes of information. On the one hand, it is necessary to evaluate the forces or deformations occurring in the stressed part and thus determine the stresses involved. On the other hand, it is necessary to appraise the consequences of these stresses in terms of failure. Both of these problems require specialized knowledge of a high order, but it is particularly the second one that is difficult. The unsatisfactory state of knowledge of this latter problem is due to a real lack of principles of causality. We do not know, in general, the combinations of circumstances which cause failure, nor do we always know what we mean, scientifically, by the term failure. It is only in the cases of extremely simple forms of stress applications, such as straight tension, and materials with extremely simple behavior, such as mild steel, that our knowledge may be called exact. As a result of

this, our conception of strength is based on these simple circumstances and we are content to extrapolate this knowledge, more or less justifiably, to more complicated cases.

THE DETERMINATION OF STRESSES

In the present discussion, the problem of determining the stresses will be passed over very briefly. It is of importance to remember that a complete knowledge of a state of stress at a point of a solid body involves nine quantities. These consist of three tensile stresses and three shearing stresses, but the latter are identical by pairs so that a total of six quantities is necessary to specify the condition of stress with respect to an arbitrary reference. Once these stresses are known, it is possible, by Hooke's law, to determine a corresponding set of strains. It is often advantageous to select for reference the particular directions which make the shearing stresses zero. The stresses acting on the sides of a cube orientated in this manner are called *principal stresses;* the corresponding *principal strains* are obtained from Hooke's law.

It is easy to find all types of stress applications in a steam-turbine. Cylinders and shells under internal pressure are subjected to stresses in the plane of the bounding shells, but the application of stress is strictly three dimensional, since shearing stresses at 45 degrees to the plane of the shell are not excluded. Supporting details of the stationary parts are, of course, subjected to three-dimensional stresses in most cases. The bolting is generally a problem of straight tension, but the flange details often involve complicated combinations of bending stresses, usually three dimensional.

Of particular importance are the bore stresses of the rotor. In the case of thin axial disks, these have the aspect of one-dimensional stresses; but, in general, the application is more complicated. The bending and torsion stresses of the shafting constitute another group of stresses which may be of importance.

The blade stresses form another important group of problems. The stresses in the blade proper are due to centrifugal forces, steam forces, and inertia reactions from vibrations. In general, the essential stresses are straight tension and bending.

The root stresses in the blade fastenings represent a difficult type of stress applications, the magnitudes of which frequently depend on accuracy of machining, methods of assembly, and so on.

The magnitude of these stresses may be difficult to determine, but given a definite set of conditions a definite solution is always available. Not infrequently, mathematical methods are of little avail; graphical and mechanical integration methods are then brought into action. Lastly, the experimental methods, notably the photo-elastic method, are gradually receiving merited attention. There is thus no idle boast in the statement that the evaluation of the stresses is always possible with practical limits of accuracy.

Before proceeding with the problem of failure, it is important to point out a difference in the type of stress thus obtained, which is sometimes neglected. It is necessary to distinguish between a state of stress which disappears through relaxation of the structure and a state which persists regardless of the ensuing deformations. To the first group belong such stresses as the assembly stresses in a disk shrunk on a shaft. The centrifugal stresses in the disk, when rotating, form a representative example of the latter type. It is obvious that these types of stresses must be evaluated differently in appraising their contributions to failure. Not infrequently the first group of stresses may be neglected altogether, as non-essential to the phenomenon of failure; the resulting simplification of the stress problem is an important help. The usual method of neglecting stress concentrations in ductile materials under steady stress is an example of this.

THE PREDICTION OF FAILURE

The state of stress is now assumed to be known from the three principal stresses at each point of the structure. The problem of failure consists in establishing the particular values of these stresses at which failure will occur. It is an outstanding feature of this problem that after a century of research there are still some half a dozen theories on the subject, some less plausible than others, but none of sufficient merit to remain conclusive.[10]

The real difficulties of the problem are due to the fact that the definition of failure must be suited to the case at hand; not only to the material under stress, but also to the type of stress involved. Soft steel will fail by yielding under constant stress, but under conditions of variable stress it will crack like cast-iron. Marble and similar brittle materials will flow like lead under appropriate conditions of stress. Moreover, unlike the problem of efficiency, the problem of

failure is not solved by direct experience. No designer would outlive truly instructive failures of large turbines, nor would the interpretation of the evidence be really conclusive. Thus, it is necessary not only to suit the definition of failure to the properties of the material and the state of the stress, but also to the methods by which the properties of the materials have been tested.

Our knowledge of the physical properties of our engineering materials is derived chiefly from tests under one-dimensional stress. In this manner the materials have gradually been divided into two major groups—*brittle materials* and *ductile materials.* A satisfactory distinction between the two groups is yet to be found, but a reference to the most important representatives, cast-iron and mild steel, is sufficiently illuminating. When judged from the viewpoint of difficult problems of strength, only the ductile materials possess reliable properties, so that the brittle materials may be left out of the present discussion.

The conditions of use have been segregated into two main groups—*normal temperatures,* from room temperatures to about 300 degrees F., and *elevated temperatures,* above that range.

The mode of application of stress has been segregated into *steady stress, alternating stress,* and *impact stress.*

The type of stress for each one of these conditions of use and mode of application of stress may be classified into *tension and compression, shear,* and *combined stresses.*

The knowledge available at the present time does not cover more than a small part of this field. The properties under steady and alternating tension, and compression and shear, are known fairly well for most materials at normal temperatures. The properties under steady tensile stress at elevated temperatures are somewhat imperfectly known. The properties under combined steady stresses are fairly well known for normal temperatures, but practically unknown for elevated temperatures. It is in this field that the *theories of strength* have been tested. The experimental evidence available at the present time for ductile engineering materials appears to be in favor of a relation between principal stresses somewhat more complicated than that given by the maximum shear theory.[11] The deviation from the maximum shear theory is comparatively insignificant, however, so that the maximum shear theory is gradually becoming the accepted method of

evaluating failure in cases of combined stress. Another reason for this is that the circumstances encountered in cases of alternating stress, and the conditions under elevated temperatures, do not appear unreasonable in the light of the interpretation furnished by this theory.

THE MEASURABLE PROPERTIES OF DUCTILE MATERIALS

Tensile Test. The tensile test is the chief source of information for all conditions of steady stress. Its net result is presented in a *stress-strain curve* which furnishes information of two kinds. The elastic range and the beginning of the plastic flow define the stresses at which permanent deformations begin to occur. In this connection many definitions for a limiting stress have been presented, such as proportionate limit, elastic limit, and yield-point. At the present time, the yield-point is usually considered the key stress; the others have the objection of being difficult to measure exactly. In defining the yield-point, it is necessary to refer to the shape of the stress-strain curve at the beginning of the deformation. It is becoming customary to define the yield-point in such cases as the stress at which the permanent deformation amounts to 0.2 per cent.

The remainder of the plastic deformation yields information of a more qualitative nature. The *ultimate strength* is a somewhat idealized stress taken as the ultimate load at the point of rupture, divided by the original area. It is obvious that it can have no direct bearing upon failure. However, it has been found of value in giving a composite figure of strength and ductility. The elongation expresses the specific lengthening of the gage length when the test-piece breaks; the reduction of area represents the specific reduction in cross-sectional area at the point of rupture. The significance of the reduction of area is very great and appears to extend beyond the scope of the tensile test. The elongation is a somewhat unsatisfactory figure since it depends upon the selection of gage length.

Elevated Temperatures. The earliest information on the properties of the materials at elevated temperatures was obtained by ordinary tensile tests. Even to-day the tensile test is probably the most important means of high-temperature testing. As the temperature increases, the materials undergo more or less far-reaching modifications. The figures of strength generally drop with increasing tem-

peratures, while the figures of ductility increase. At 1000 degrees F., practically all of the materials available at present are profoundly modified. Fig. 3 and 4 show curves of strength and ductility for two typical materials.

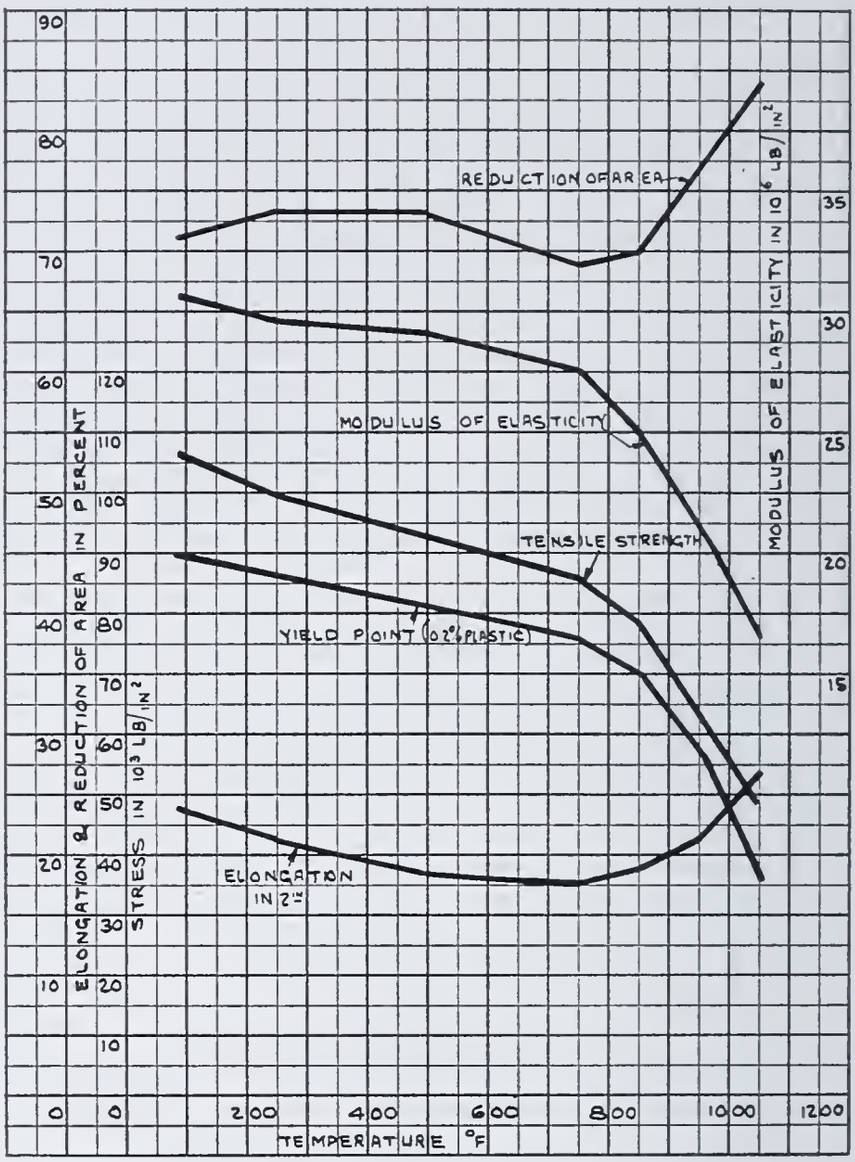


Fig. 3. Physical Properties of Stainless Steel.

The actual reduction in strength is not the most important change, however. The usual permanence of the elastic properties is destroyed and the materials behave approximately as amorphous materials. This phenomenon of creep is of greater importance than the reduction in strength, and must be considered in the dimensioning parts for high-temperature turbines. Unfortunately, the available knowledge is entirely insufficient to make definite predictions of creep in most cases, nor does it seem likely that exact knowledge will be available very soon. Creep under combined stress is also somewhat

of a mystery; at the present time it is generally assumed that only the maximum shear influences the creep.

Even more subtle are certain other changes, which up to this time have been only imperfectly demonstrated. The change known as

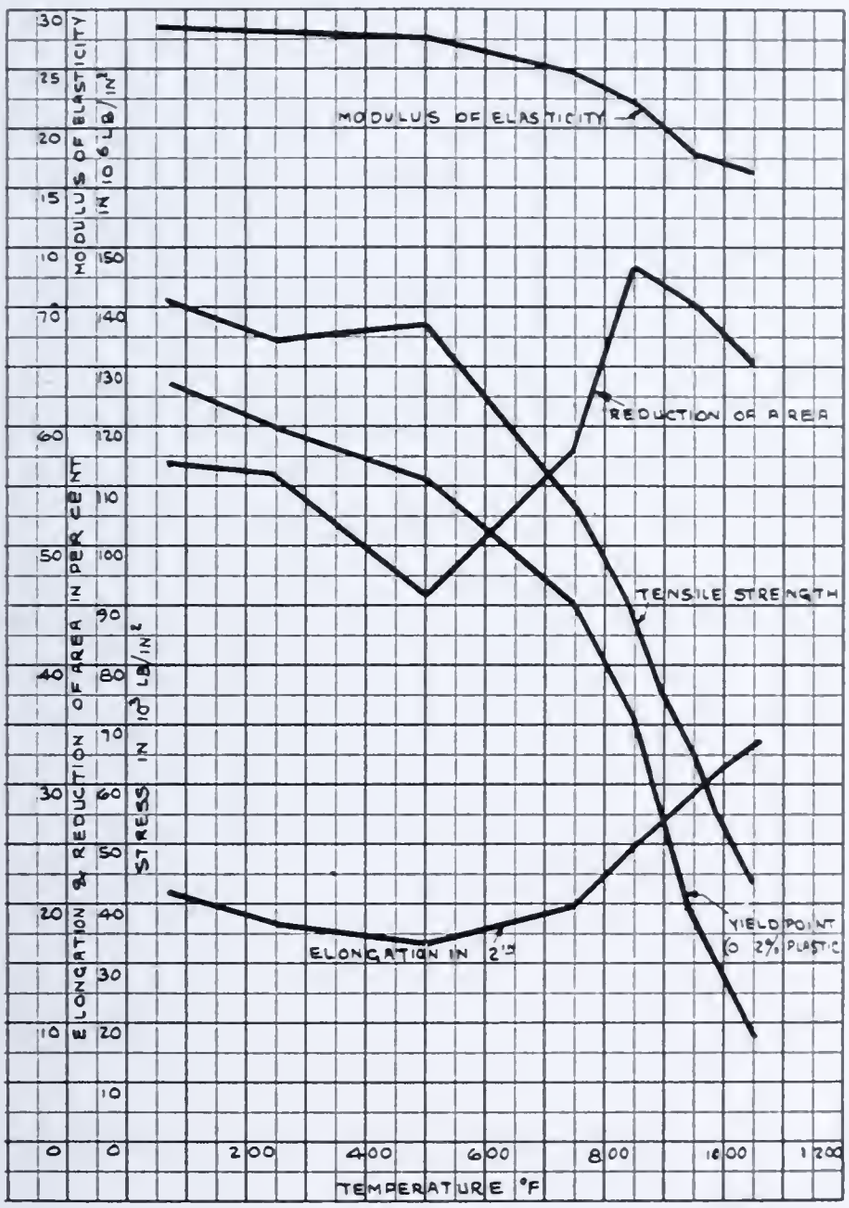


Fig. 4. Physical Properties of Chromium-Nickel Steel.

carbid spheroidization is beginning to receive attention, particularly because it has been found to affect the resistance to creep. Other phenomena, such as caustic embrittlement and similar disintegration of grain boundaries, have also been associated with service at high temperatures.[12]

These new points of view have only recently been added to the already long list to be considered by the turbine designer. A com-

mendable degree of conservatism has been shown, but it appears that in many cases the fear of creep has been permitted to dominate the problem too far. The modification of many materials at temperatures between 500 and 800 degrees F. is in some respects definitely desirable. The ductility increases, and with it the ability to obliterate sharp concentrations of stress. In addition, the fear of creep has, in many cases, defeated its own object by injecting objectionable temperature stresses due to indiscriminate increase in the dimensions of the parts involved. Naturally, there are many cases, such as stresses in bolts, where the results of creep tests may be applied most directly. In most cases of relaxation, however, it is only the average stresses over certain cross-sections which need to enter into the creep problem.

Variable Stress. Tests of variable stress are usually made in special machines, but for purposes of fundamental principles it is better to regard the test as a modified tensile test. The fundamental information is obtained by applying alternating stress through which the endurance limit is obtained. This represents the stress below which failure will not take place even for very large (10,000,000) numbers of reversals. Failure is necessarily of a nature different from that in ordinary tensile tests, but it is possible to speak of a certain parallel between ultimate strength and endurance limit.

An outstanding and important feature of variable stress applications is the importance of local concentrations of stress. Failure is determined approximately by the maximum localized stress. This constitutes the most difficult aspect of the phenomenon of variable stress.

The simultaneous existence of alternating and steady stress leads to various combinations of pulsating stress. A scant amount of experimental information is already available. In general, failure under alternating stress will occur sooner when a steady stress is added, but no very definite law of superposition seems to exist. Fig. 5 illustrates this phenomenon for 0.53 carbon steel.

Impact Stress. If in a tensile test-piece the stress be increased to very large values in an extremely short period of time, a fundamentally different behavior will be observed. The outstanding aspect of failure under such condition of impact is that rupture takes place without plastic flow. The practical method of carrying out the tests

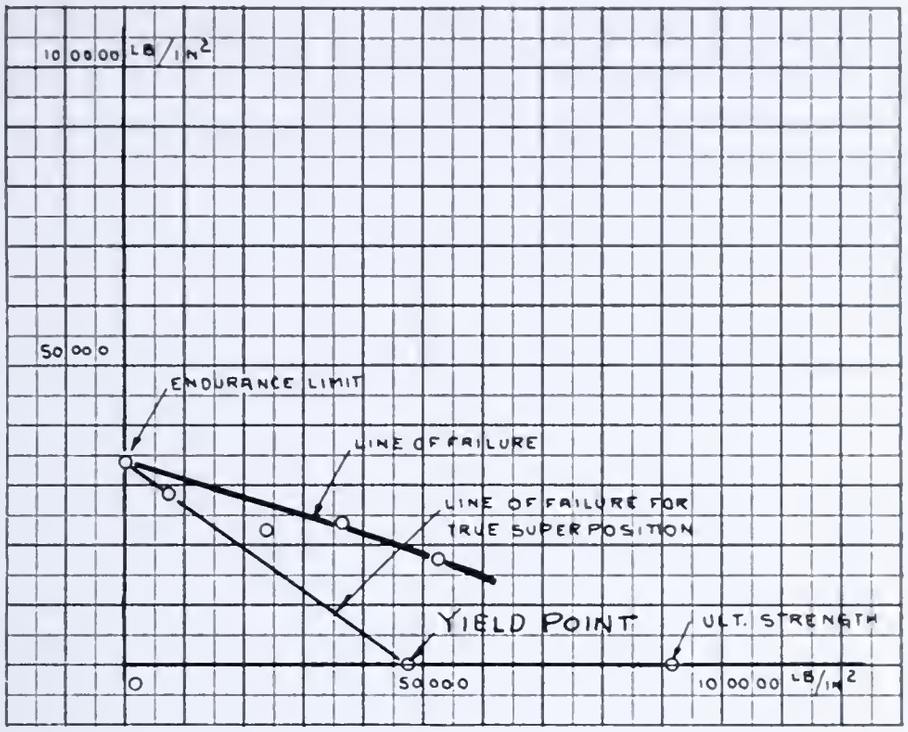


Fig. 5. Combined Steady and Variable Stress in Carbon Steel.

is by breaking a notched bar in bending, and recording the work done in foot-pounds. The value thus obtained is the impact strength. The significance of this figure is insufficiently understood, but it is associated with the cohesive properties of the material. It is a very sensitive indicator of certain faults in heat treatment and it will also reveal the existence of embrittling modifications of the crystalline structure. Ordinary tensile tests of notched specimens have been used successfully for the same purposes.

FACTOR OF SAFETY AND WORKING STRESS

The designer's appraisal of the combination of the conditions of use, the mode of application of stress, and the type of stress, coupled with the material in use, is expressed by the *working stress*. The safety of the structure is expressed by the *factor of safety*. The latter term is intended to indicate the degree to which the potential strength of the structure is in use. Obviously, it is necessary to define this potential strength before a satisfactory definition can be obtained. This has not always been the case, and the result is that a great deal of confusion exists with regard to the "safety" of a structure.

In the case of the tensile test, it is evident that, for ductile materials, the yield-point represents the limit of strength; the factor of safety, consequently, is the ratio of yield-point to actual stress. Some-

thing would undoubtedly be gained by expressing the safety of the structure by the "factor of utilization," the inverse of the factor of safety; 100 per cent. utilization would thus represent a stress equal to the yield-point. It is evident from the above that local concentrations of stress do not affect the safety for ductile materials under steady stress.

Under alternating stress, the factor of utilization is based on the endurance limit, local stress concentration now playing a definite part. Simultaneous application of steady and alternating stress requires a further definition. As mentioned above, no true condition of superposition seems to exist between variable and steady stresses existing simultaneously. In spite of this, however, it is becoming customary to determine the factor of utilization by direct superposition. Thus, if a material having a yield-point of 60,000 pounds per square inch, and an endurance limit of 40,000 pounds per square inch is subjected simultaneously to a steady stress of 30,000 pounds per square inch and an alternating stress (including stress concentration) of 10,000 pounds per square inch, the factor of utilization would be $0.50 + 0.25 = 0.75$. The factor of safety would be $1 \div 0.75 = 1.33$.

The conditions at elevated temperatures require no further definitions until the phenomenon of creep becomes important. It is now no longer a question of strength, but of stability of dimensions; the problem of creep completely dominates the situation. The permissible stresses are determined on an assumption of the life of the machine and the rate of creep during its life. On this basis, practical creep rates have been proposed for various turbine details, varying from 10^{-9} per hour for rotor disks to 10^{-7} for pipe joints.[13]

The conditions of combined stress are dealt with, as indicated above, on the basis of the maximum shear theory. The problem then resolves itself into a determination of the maximum shear stress. Until further knowledge is available, it seems justifiable to base the treatment of variable stress, as well as the cases of elevated temperatures, on the same theory.

The actual values of the factors of utilization vary so much from detail to detail that no very definite figures can be given. When a well known ductile material is subjected to accurately known steady stresses, a maximum stress of 75 per cent. of the yield-point can be

justified. This can be regarded as the extreme limit of utilization of present-day materials. Most turbine details are designed for much lower factors of utilization, however.

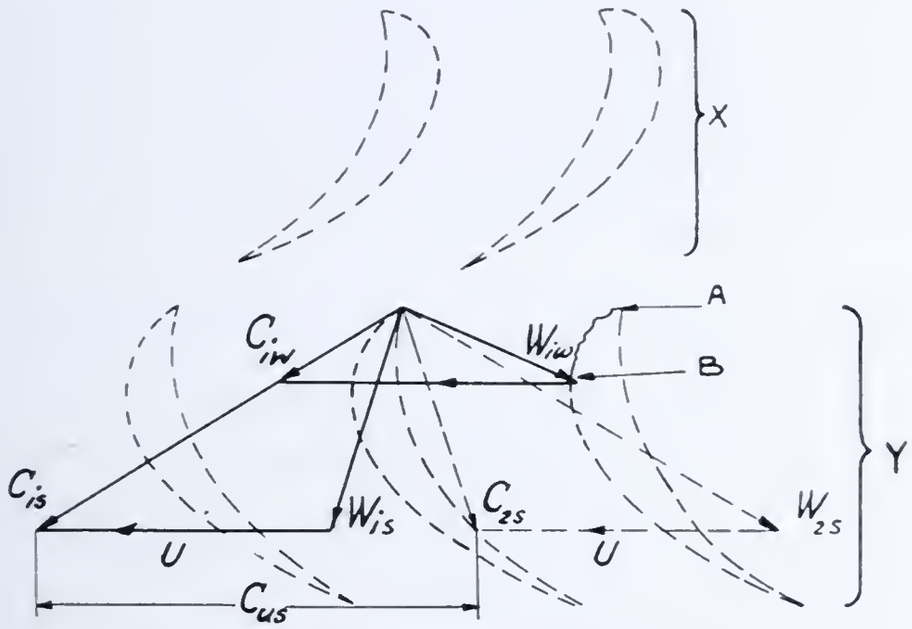


Fig. 6. Blade Erosion.

THE PROBLEM OF EROSION

Referring to Fig. 6, the steam leaves the stationary row X and enters the rotating row Y with the absolute velocity C_{is}, and the relative velocity W_{is}. It expands in the rotating row to the relative velocity W_{2s} and the absolute velocity C_{2s} so that the change in momentum for a unit mass of steam is C_{us}. The moisture, at the moment of precipitation, has the velocity of the steam C_{is}, but the drops immediately begin to be retarded, and they enter the rotating row with a velocity $C_{iw} < C_{is}$. The relative velocity of this water is W_{iw}, the velocity by which the water drops will impinge on the blade.

The immediate consequence of this retardation of the moisture is a certain loss of energy. The primary cause of the loss is the change in momentum of the moisture; in addition, however, there is a disturbance of the flow of steam through the rotating row, causing additional loss. It is not difficult to show that the loss of energy is at least

$$P_w = P_o \left(1 + \frac{U}{C_{us}}\right) \left(1 - \frac{C_{iw}}{C_{is}}\right) (1 - x)$$

where P_o is the work done on the rotating row in question and x the quality of the steam.

In this expression C_{iw}, the water velocity, is the only unknown quantity. An approximate value is obtained by observing the width of the eroded band A-B. From such observations it may be concluded that the velocity of the water does not, in general, exceed one-third of the velocity of the steam. The velocity of the water depends principally on the size of the drops of moisture, which in turn is a function of the pressure. Theoretical reasoning based on this phenomenon gives, for the water velocity, results which give a certain semblance of agreement with observed values.[14]

Independently of this, however, the drops experience further retardation after they enter the path through the rotating row. In consequence of this, it seems reasonable to conclude that the moisture loss in most cases corresponds to an absolute water velocity of zero. One per cent. of moisture will thus cause at least $\left(1 + \frac{U}{C_{us}}\right)$ per cent. of loss for the row in question.

Another equally serious consequence of the retardation of the water is the erosion of the back of the rotating row, Y. The eroded portion will extend from A to B, with the most intensive erosion at A. The amount of erosion is a function of both the degree of moisture and the impinging velocity. Presumably, the size of the drops and the pressure also enter into the phenomenon, but the actual relationship is not very well understood as yet. There is no uncertainty about the seriousness of the problem, however, because this erosion is at the present time the chief factor in limiting the peripheral speed, and thus the exhaust annulus, of large turbines.

The erosion problem has been given considerable study in the last few years. The most important methods of approach are (1) increasing the absolute velocity of the water by reducing the size of the drop; (2) draining the moisture from the blading; and (3) increasing the erosion resistance of the blading material. No satisfactory method has been found to accomplish the first object, but a certain measure of success has been obtained by draining out the precipitated water. A somewhat superficial check of one machine some time ago indicated that about 25 per cent. of the total moisture precipitated in a row may be drained off by a moisture catcher developed several years ago by the Westinghouse Electric and Manufacturing Company.

The most important and most effective aspect of the erosion problem, however, is to make the blading impervious to the bombardment of the water drops. An exhaustive description of all experimental work that has been done on this subject would fill volumes, but at the present time fairly simple conclusions can be made. It has now for some time been agreed that, beyond the use of stainless steel, it is impractical to employ a blade material of sufficient inherent hardness to be impervious to the erosion. This leaves as the only alternative a protective shielding of some kind.

Chromium plating in thicknesses up to 0.005 inch has been used with a certain measure of success. It is a very expensive method, however, and the question of renewing the coating is troublesome. In addition, arguments have been advanced in regard to embrittling actions of these extremely heavy platings. This is not yet fully explored, but recent tests indicate that a certain embrittling may occur.

Nitriding the blades on the inlet edges has also been used with satisfactory results as far as erosion protection is concerned. Nitriding the thin edges leaves them very brittle, however, and the method has not come into general use. Nitriding the thick inlet edges only is a possibility, and when applied in this manner the method has attractive possibilities.

Separate shielding strips applied to the blades by welding or soldering were used by Parsons in England several years ago. The method has been very thoroughly investigated in America and it is now regarded as the most favorable solution. A tremendous variety of protective shieldings has been tried, of which may be mentioned tungsten, tantalum, "stellite," "contracide," "rezistal," and numerous others. Tantalum and "stellite" (particularly the latter) are the most promising, having given excellent results in service on some large units. With this method of protection, blades with tip speeds exceeding 1200 feet per second will now give the same service as ordinary stainless steel blades for tip speeds of the order of 900 feet per second. Fig. 7 illustrates a shielded blade.

A great deal of valuable operating experience is now being accumulated on the subject of erosion. One of the turbines operated by the Duquesne Light Company, for example, is equipped with some thirty different kinds of shielding materials.

Fig. 7. Low-Pressure Spindle Blade with Erosion Shield.

The problem of erosion protection received its most important impetus by the development of a rational erosion tester. The Westinghouse Electric and Manufacturing Company has now had such a tester in operation for some time and some valuable results have been obtained. The curves in Fig. 8 show comparative results for stainless steel and "stellite" for impinging speeds of 1000 and 1200 feet per second. The evidence in favor of "stellite" shielding is very pronounced. Of particular interest is the fact that this erosion tester has

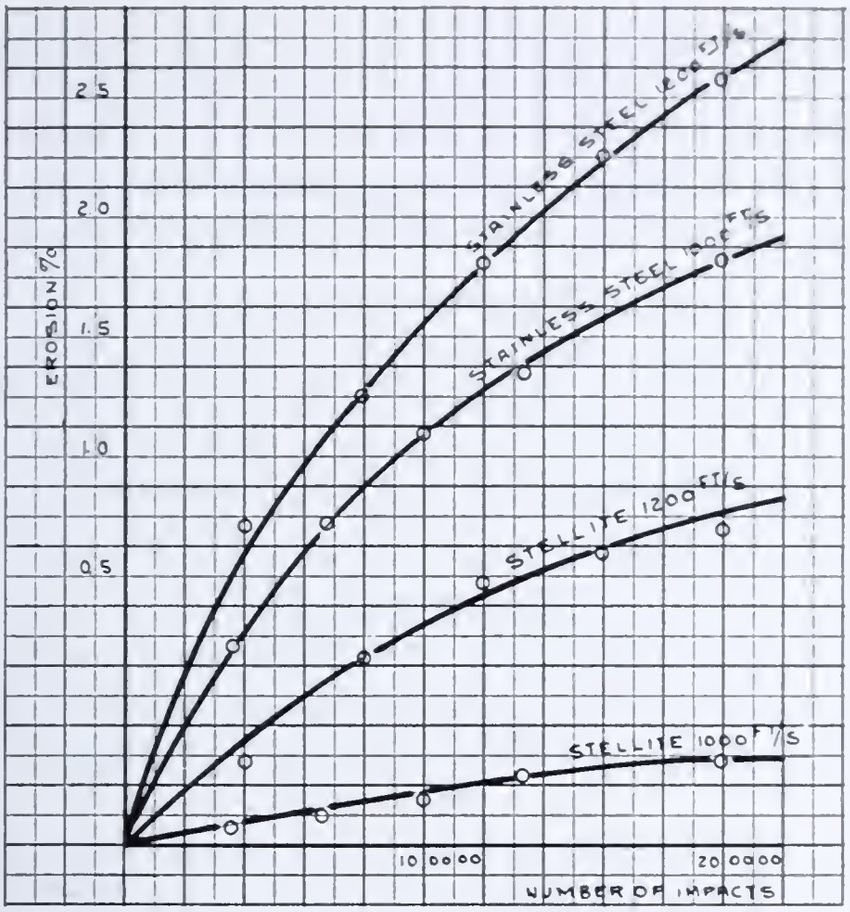


Fig. 8. Typical Result of Erosion Test.

so far confirmed in every detail the evidence gathered from machines in actual operation.

THE PROBLEM OF MATERIALS

It is safe to state that no one factor has affected the development of steam-turbines more profoundly than the metallurgical problem. The program has not always been rational, the materials have not always been judged by rational standards, and many expensive developments have led to blind alleys. The progress has, nevertheless, been outstanding, and important innovations are constantly being made.

The most vital part of this development has concerned the high-strength materials for the rotating parts. The use of carbon steel is still important, particularly for the generators, but several important alloy steels are now the most important rotor materials.

Nickel-molybdenum steel (2.5 per cent. nickel, 0.25 per cent. molybdenum, and 0.4 per cent. carbon) has gained an important place for this purpose. It is now possible to obtain forgings in weights of 75,000 pounds with a yield-point of 60,000 pounds per square inch

and a reduction of area of 40 per cent. in the tangential direction near the rotor ends. The development has required rotor forgings of still greater weight, however, so that certain rotor constructions have been made with a transverse joint at the high-pressure end. On more recent constructions this joint has been moved to the low-pressure end instead.

While these constructions have given a good account of themselves, it is, nevertheless, desirable to eliminate such joints. The solution of this problem appears to be to mount the heavy blade rows on disks shrunk on the shaft. The central part of the rotor can then be made of a relatively inexpensive carbon steel, except for high-temperature applications, where an alloy steel must be used. In the comparatively small sizes required for these disks, the nickel-molybdenum steel (with the composition mentioned above) may be given a yield-point of 80,000 pounds per square inch and a reduction of area of 40 per cent.

One of the outstanding properties of the nickel-molybdenum steel is that in large forgings the physical properties are maintained under high temperatures. The figures of strength are better sustained at the higher temperatures than in the case of any other similar material, and the creep is less. It is not difficult to obtain small pieces of special alloys with superior physical properties, but when the forging problem is considered with the risk of segregation, the nickel-molybdenum steels have been found outstanding.

The important subject of blading materials has not been changed by any fundamental development during the last few years. Stainless steel (12 per cent. chromium and 0.5 per cent. nickel) is accepted as the best material for practically all applications. Its qualities of strength are such that it is generally used for the large low-pressure blades as well. The austenitic materials (for example, 20 per cent. nickel, seven per cent. chromium) also have their applications where corrosive conditions are detrimental to standard materials. The difficulty of machining, however, is a serious handicap to the use of these materials.

The process of manufacturing these large blades is an important problem. Forging has been the common method for the more complicated blade shapes, but milling is now gaining in importance. Con-

siderable progress has been made recently with milling of blades from special rolled shapes.

The subject of blade erosion has brought about considerable development of shielding materials of controllable hardness.

The standard nitriding steels, especially the chromium-aluminum-molybdenum type, possess very interesting possibilities. The erosion protection is very satisfactory and their fatigue properties are above those ordinarily found for very hard materials. An equivalent Brinell hardness in excess of 900 is now obtained. Where the shape lends itself to the process it appears very promising.

"Stellite" represents a group of alloys composed of cobalt, tungsten, chromium, and iron, which also possess outstanding properties in this respect. The Brinell hardness is of the order of 550, after the securing to the blade. Greater hardness may be obtained, but then the brittleness becomes too great. Originally, attempts were made to deposit "stellite" by welding to the back of the blades, and this method has been applied successfully on blades of limited lengths. For very long blades, however, experience has shown that attaching rolled strips by silver soldering is a more satisfactory method.

Hardened tantalum has also given good performance with regard to erosion, but this material is somewhat too expensive; the hardness generated by the usual treatment is very shallow; and the permanence of the protection is not yet proved.

One of the most outstanding recent developments is a welding rod for arc welding of stainless steel. This has turned out to be an important improvement, and arc welding is now gradually replacing silver soldering in certain important blade details. The welding rod used for this purpose consists of 18 per cent. chromium and eight per cent. nickel and is coated with a special flux.

Another important development is the depositing, by arc welding, of "Monel" metal, stainless steel, "stellite" and other materials on valve-seats. By this process, it is possible to use cast-steel for the valve body, on which may be deposited a seating material of suitable qualities.

MISCELLANEOUS PROBLEMS

VIBRATION

Vibration has always played an important part in steam-turbine development. It is the most frequent operating trouble, and a superficial judgment of the performance of a machine invariably concerns the smoothness of its operation. Errors of judgment in the design of a machine are most frequently punished by vibration troubles.

Most vibration troubles are caused primarily by unbalances in the rotating masses. The ways by which these unbalances are brought about are very numerous, however, and many are as yet only imperfectly understood.

The process of balancing the rotating masses was the first to be subjected to rational study several years ago. Balancing machines for various types of rotating bodies were developed and rational methods were adopted for correcting the balance of large machines already in operation. As a result of this work, it may be said that there are now very few cases where the balancing process in itself offers serious difficulties.

The permanence of balance and alinement is a subject which has been given a great deal of attention during the last few years. It was observed long ago that on certain machines the intensity of vibrations varied in a highly erratic manner. Vibration troubles of this type are often baffling. Certain instances will always remain mysteries, while others have been corrected by seemingly trivial changes.

Certain details of design have been regarded as of particular importance. One of these details is the concentricity of the bore of a rotor spindle with a central hole. It is evident that a temperature gradient between the inside and the outside in such a case will give rise to a change in curvature of the neutral axis of the spindle. Considerable importance has been attached to this concentricity, therefore, but no quantitative evaluation of this effect has been made. The problem is complicated if an attempt is made to obtain an accurate solution for an actual case. A reasonably accurate conception of the danger of such concentricity may, however, be obtained in the following manner.

Consider a long cylinder of the cross-section shown in Fig. 9 and let there be a temperature rise, $\triangle t$, between the inside and the outside. It is immaterial whether $\triangle t$ is negative (as shown in Fig. 9)

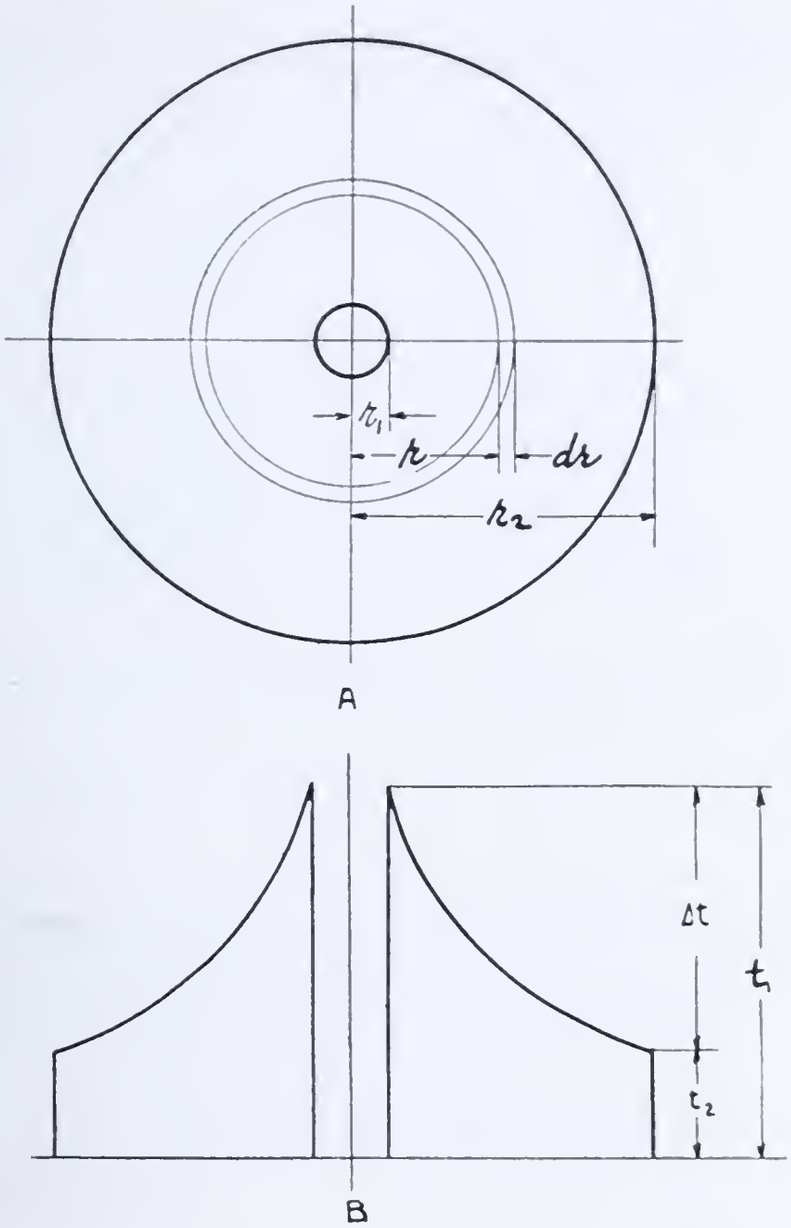


Fig. 9. Temperature Distribution in Shaft.

or positive. In the former case, the outer fibers of the cylinder will be in tension and the inner fibers in compression, but no curvature of the cylinder will take place. Now assume that the hole is bored eccentrically a small amount. The distribution of temperature will remain essentially the same, but the stresses will now cause a bending moment about the axis y-y. The change in curvature $\left(\frac{1}{\rho}\right)$ may be determined if certain assumptions are made with regard to the temperature distribution. If it be assumed that the temperature difference, $\triangle_t$, is the result of a steady flow of heat from the inside to the outside, and, if the coefficient of thermal expansion be denoted by α, the change in curvature will be found to have the value $\frac{1}{\rho} = f\left(\frac{r_1}{r_2}\right)\frac{\alpha \triangle t\, e}{r_2^2}$, where $f\left(\frac{r_1}{r_2}\right)$ is a function of the ratio $\frac{r_1}{r_2}$.

The following table gives a few values of this function:

$\frac{r_1}{r_2} =$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
$f\left(\frac{r_1}{r_2}\right) =$	0.187	0.232	0.251	0.255	0.249	0.236	0.219	0.202

For example, if $\triangle t = 200$ degrees F., $r_2 = 5$ inches, $r_1 = 2$ inches, $e = 0.025$ inch and $\alpha = 6.5 \times 10^{-6}$ (steel), $\rho = 3 \times 10^6$ inches. This curvature is not large, but if it occurs over a considerable portion of the length of a large turbine spindle the ensuing unbalance and change of alinement (Fig. 10) may not be admissible.

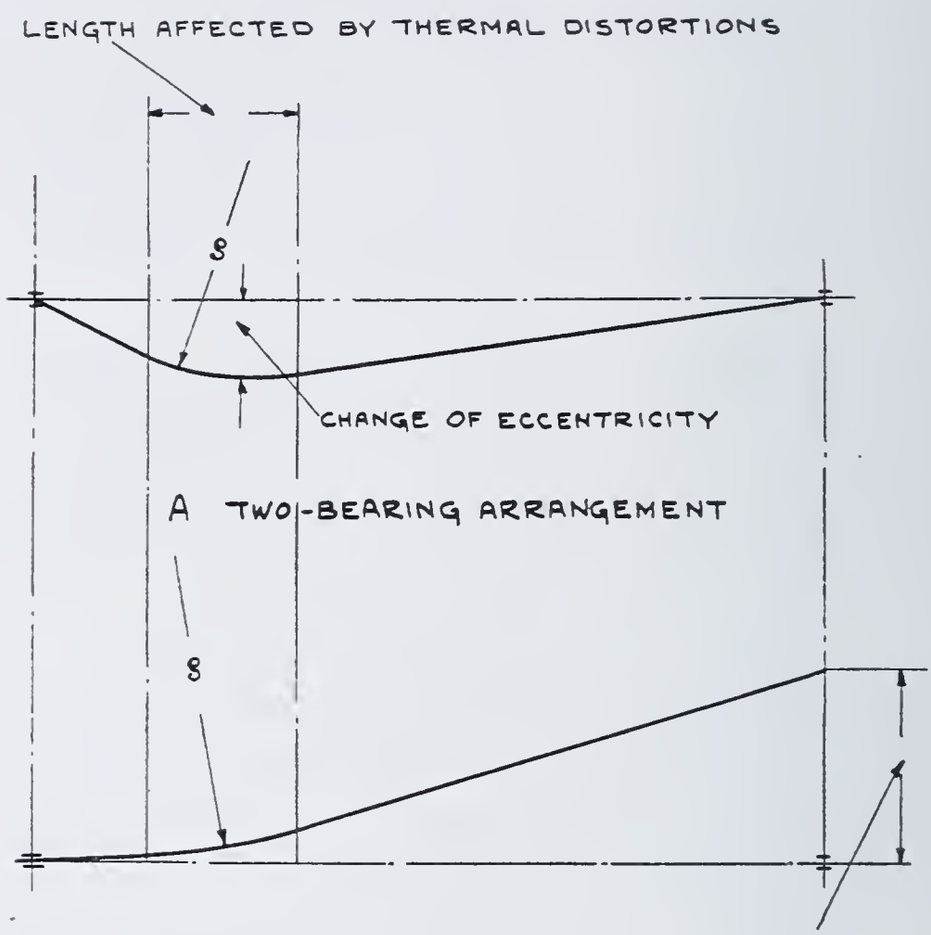


Fig. 10. Effects of Thermal Distortions of Shaft.

For this reason the accuracy of central bores of spindle forgings is now held to fairly close limits.

Another important source of troubles of a similar nature is faulty design of the stationary parts to take care of thermal expansion. In high-temperature machines, the thermal expansions of the various parts of the turbine may be very large. The suspensions of

the high-pressure cylinders and bearing pedestals must be such that this expansion is facilitated. A great deal of progress has been made in this respect during the past few years.

Fig. 11 shows an arrangement that has been used with outstanding success on several recent single-cylinder machines operating

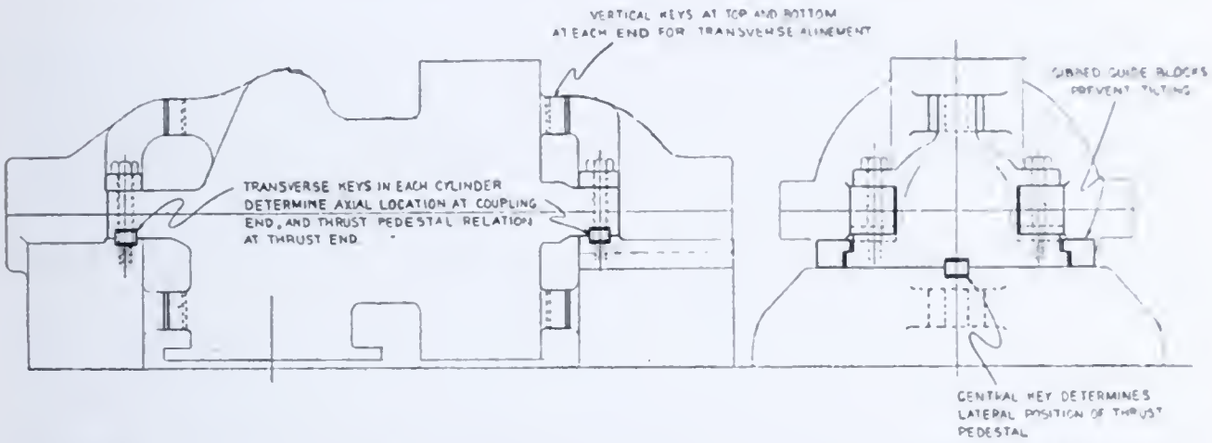


Fig. 11. Schematic View of Cylinder Support for Single-Cylinder Machine.

at 825 degrees F. inlet temperature. This arrangement has been evolved for end-tightened machines where the axial alinement between cylinder and spindle is of particular importance.

Another feature of great importance in this connection is the necessity for commensurability of thermal properties for spindles and cylinders. The best degree of permanence of alinement is attained if the heating and cooling curves of the cylinder and the spindle are identical.

When details of the above nature have been taken care of satisfactorily, there is still the problem of designing the rotating and stationary parts in such a manner that resonance is avoided. This problem is also one of very large scope, and it is only in certain specific aspects that the problem can be taken care of by routine design methods.

The problem of resonance in rotating disks, so acute only a few years ago, belongs to this class, although disk troubles are encountered occasionally even to-day. The circumstances leading to resonance are well known, however, and troubles can usually be attributed to a neglect in not using the available knowledge. The problem of blade vibrations, on the other hand, is much farther from its ultimate solution. Here we know less about the frequencies and magnitudes of the impressed forces; and, moreover, the possible modes

of vibration in groups of long blades are very numerous. Under such circumstances, the designer is often at sea in his choice of fundamental considerations of design. Nor is direct experience a very valuable guide. At most, it can prevent the recurrence of similar blade failures, but with the difficulty of accurate observations it rarely gives aid in predicting the behavior of fundamentally new designs.

Under these circumstances, it has become necessary for the turbine manufacturers to obtain the required experimental results by model tests under laboratory conditions. A great deal of such experimental work is going on at the present time. The most rational methods subject the assembled groups of blades to impulses of known intensity and frequency, while the resulting motions are observed. The old hammer test is simple, but is still a useful form of blade testing. The motions involve all possible modes of free vibrations, where all natural modes are excited simultaneously. Very useful results for comparison of different blade materials and details of lashing have been obtained in this manner. The agreement between results obtained in service and these hammer tests is often surprising.

The question of critical speeds of the rotor structure as a whole has ceased to have the importance that it had several years ago. For a long time the fear of passing through critical speeds actually retarded the development towards large units. Gradually, the demand for lengthening of the machines, particularly the generators, became so insistent that the restrictions due to critical speeds were waived. No particularly deplorable consequences can be traced to this step, although even to-day many turbine designers do not deliberately design their machines to pass through the critical speeds. Many designs are still in a stage where this is not even necessary.

The introduction of end tightening of reaction blading brought about a simplification of the problem of passing through a critical speed, since the vicious results of rubs with radial blade contacts in the middle of the machine are eliminated.

The problem of critical speeds of rotors for very large machines is further complicated by the fact that the structure of the entire machine takes part in the vibrations. The relative rigidity of foundations and bearing supports diminishes as the size of the machines increases, so that for the large machines the actual critical speeds are much different from the calculated. The problem must now be

treated as a foundation problem, and the phenomena become very complicated. This is realized from the well known fact that any large machine passes through a number of critical speeds in coming up to its operating speeds. Several other resonance combinations above the operating speed add to the chances of coincidence with the operating speed.

It is not very often that a complete foundation analysis can be made, and the structure frequently is so complicated as to preclude exact analysis. Experience has shown that lateral and vertical vibrations can be treated as independent, on which basis it is possible to construct a dynamical model of the system.

Experience can be a reliable guide in these problems only if the observations are made systematically. The art of vibration measurements has progressed enormously in recent years, and the problem of making reliable observations no longer presents real difficulties. Observations of a scientific nature require elaborate equipment in the way of graphically recording instruments, of which there are now several excellent ones on the market. One type of observation which is easily made and which is very useful deserves particular emphasis. This is the resonance curve giving the relation between frequency and amplitude at different points for different directions of motion.

THE STARTING PERIOD

It is a well known fact that most mishaps with large turbines in the way of heavy rubs occur during the starting period. This is evident from the fact that it is during the starting period that the temperatures are readjusted from room temperatures to operating temperatures. Most of the considerations given to the subject of distortions in the previous part of this paper apply with particular emphasis to the conditions under the starting period.

This problem has influenced turbine designs in several respects during the last few years. The use of the turning gear for rolling the spindle at low speed until the temperatures are stationary and the distortions gone is now general for large units. The eccentricities and distortions are checked carefully before the turbine is allowed to run up to high speeds.

An important development has been undertaken recently in connection with this last point. It has for some time been recognized

as desirable to obtain graphical records of these distortions during the starting period, but no suitable instruments have been available. The Westinghouse Electric and Manufacturing Company has recently completed a program of development of such instruments whereby it is now possible to obtain a graphical record of the eccentricity of the shaft at various points, the axial setting of the spindle, the expansion of the pedestals and cylinders, and the vibrations of various points of the turbine structure.

These instruments employ an electrical measuring circuit, the characteristics of which respond to changes in the magnetic circuit. In a type of eccentricity meter now in use, there are two transformers on each side of the shaft. The magnetic path of these transformers consists partly of an unsaturated iron core, partly of the shaft proper, and partly of the air-gap between the transformers and the shaft. By the proper choice of electrical quantities, the magnetic reluctance of the circuit is centered in the air-gap. As shown in Fig. 12, the pri-

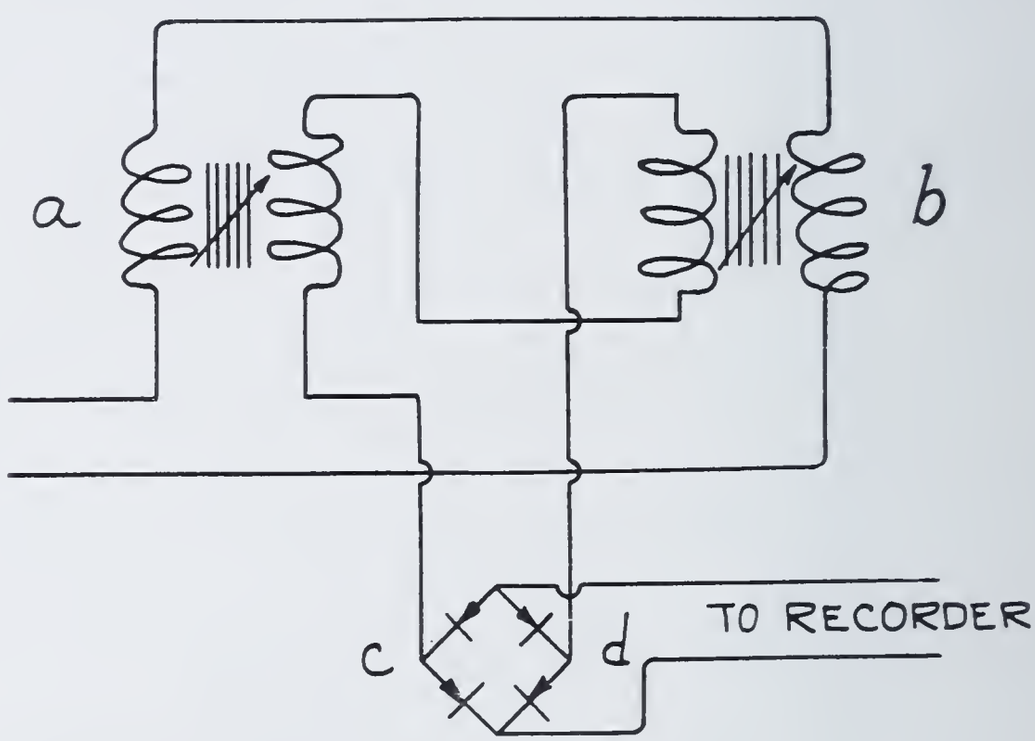


Fig. 12. Arrangement of Measuring Circuit.

maries, a and b, of the transformers are connected in series with a high-frequency source. The secondaries are connected in parallel in the measuring circuit. With the electrical quantities balanced and the air-gaps equal, which occurs when there is no eccentricity, there is no potential difference across points c and d. When the air-gaps are

unequal, the added reluctance in a combines with the decreased reluctance in b (or vice versa), and a potential difference results at c-d. This voltage is rectified by the use of an oxid disk rectifier and actuates a suitable recorder or indicating meter. By employing the balanced magnetic circuit, there is no mechanical contact between the stationary and the rotating elements, and, in addition, temperature enlargements of the shaft do not affect the calibration. The electrical circuit has been designed for a linear calibration and is capable of withstanding severe moisture and temperature conditions without introducing inaccuracies.

Slight variations of the above principles have been applied on the vibrometer and the expansion-measuring devices, with the result that records of these quantities may be conveniently made within the desired degree of accuracy on any steam-turbine.

These observations can be made at any distance from the turbine. The calibration does not depend upon vacuum tubes or similar elements, so that complete reliability can be obtained.

In addition, a noise-measuring device enables the operator to listen for rubs in various parts of the turbine through a head telephone, located at any distance from the turbine.

By these instruments the starting and operation of the large modern aggregates has been placed on the rational basis which it deserves.

BEARINGS AND LUBRICATION

No truly outstanding improvements have been made recently in this group of problems. The Kingsbury thrust-bearing placed the design of the thrust-bearings on a rational basis, and very few modifications of a fundamental nature have been made in their design for a long time.

The journal bearings have subsequently been placed on the same fundamental basis and a gradual increase of speeds and pressures has taken place. In the last few years there has been a real incentive to reduce bearing lengths to a minimum by raising the bearing pressure. At the present time, only bearings under extraordinarily high loads are made longer than the diameter; and there are in successful operation many bearings where the length does not exceed 80 per cent. of the diameter. Journal speeds are up to the order of 150 feet per second and the pressures on projected area to well above 200

pounds per square inch without operating troubles that can be traced to these high values. The work done by several firms and institutions has placed the design of bearings on a rational basis.

With these high pressures it has gradually become desirable, and in some cases necessary, to lift the journals with high-pressure oil at starting. This enables the starting to take place with a minimum of throttle opening and the wiping of the bearings is prevented. The resulting complications in piping and pump equipment appear well justified.

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DISCUSSION

T. E. Purcell, *Chairman:** We have some difficulty in getting prominent engineers to come here to tell us about what is going on in the engineering field and also we have some difficulty in choosing subjects which will be of immediate interest to a large number of members of the Mechanical Section of the Society. To-night, however, we are fortunate in having an interesting subject presented by a most prominent engineer.

Every industry uses power. Most of the power used in the Pittsburgh district is produced by steam by means of the steam-turbine. The steam-turbine plays a most important part in all of the power used in this district and therefore should be of prime interest to all.

The large steam-generating units are manufactured principally by the Westinghouse Electric and Manufacturing Company and the General Electric Company, the Allis-Chalmers Company making a few.

*General Superintendent of Power Stations, Duquesne Light Co., Pittsburgh.

D. E. CUTLER:† Mr. Soderberg is to be congratulated on the very instructive and interesting paper which he has presented to us to-night. To many of those present he has undoubtedly presented a clearer picture of the problems, methods of attack, and progress of the turbine designer. I shall not confine this discussion to the particular problems described in Mr. Soderberg's paper, but will give some general ideas of the designers' problems as affected by actual operation and experience of the General Electric Company.

It is obvious that, in order to make real progress, we must deal with the facts. It has already been pointed out that the facts are not always obvious or even available. We must then turn to our best analysis, judgment, and experience. Analytical tests are continually being made on all elements of design. These involve steam and air tests to determine the efficiency of refinements of design of nozzles and buckets, special tests on bearings, packings, and steam passages entering and leaving the turbine; also tests on the structural merit of general features of design. X-ray equipment is playing an important part in determining the actual properties of turbine materials.

Improvements made in bucket design in order to obtain maximum reliability are not based wholly on research, important as it is, but on continuous study of the history of every set of buckets produced. This history is arranged and constantly studied in order to make actual operating experience available as the chief basis for the design of reliable buckets. Theory is most effective when it is assisted and checked by a complete operating history.

Let us take, for example, a turbine to operate normally on steam conditions of 400 pounds, 700 degrees F., and 28 inches of vacuum. Local conditions, however, make it necessary for this unit to carry full capacity for short periods of time with reduced steam pressure and vacuum. This introduces a problem for the designer. He must build a reliable unit. It must produce the capacity specified and give the purchaser the best economy for normal conditions. The designer selects the features, based on calculation, research, and experience to produce the best results and meet the requirements. The features contain factors of safety to give reliable, safe, low maintenance and long life. The features and factors of safety selected are to the mutual benefit and safety of the builder and purchaser.

†Compressor Specialist, General Electric Co., Pittsburgh.

This turbine, however, under normal steam conditions will pass considerably more steam than required to produce the output requested. This makes it possible for the unit to operate continuously at loads in excess of those originally intended by the designer. Operation of this character reduces the factors of safety provided, increases the steam velocities, accelerates erosion and hastens repair. The results of these conditions are, of course, modified by local operating conditions, character of steam, including percentage of moisture, amount of solids, and chemical composition.

The designer is vitally interested in the success of his product. He is anxious to understand thoroughly the local conditions. The purchaser is anxious to obtain the best results. We are sure that only mutual benefit will result from a continuance of the frank interchange of ideas between these two.

Notable advances have been made in the field of governing. Turbines driving Bessemer converter blowers are being brought up from idling speed to full speed and load in 10 to 15 seconds from a push-button located in the converter pulpit. The speed of the turbine is also varied from this point to suit operating conditions. Turbines driving blast-furnace blowers are similarly equipped for making the necessary operating adjustments from a remote point.

The progress of turbine construction is definitely linked with the materials which are available. Investigations are continually in progress to determine those best suited. As better materials are produced, they will be used to improve and advance the design.

T. E. Purcell, *Chairman:* The use of steam at 1000 degrees F. total temperature is already here. The Detroit Edison Company at its Trenton Channel plant has, for several months, been operating a 10,000-kilowatt turbine with steam at a temperature of 1000 degrees F. The results up to the present time have been very satisfactory.

It seems to me that while Mr. Soderberg did touch upon the necessity of removing moisture from the latter stages of the steam-turbine and did show us some of the schemes being used for this purpose, turbine engineers do not appreciate the seriousness of blade erosion in the latter stages due to moisture in the steam. The cost of maintenance in the latter stages of large turbines is by far the largest

item of maintenance of the entire unit. This cost is now of such magnitude as to warrant almost unlimited expenditure in research to determine preventive methods.

We have all enjoyed Mr. Soderberg's paper very much and are indebted to him for bringing it to us.

MACHINE CONTROL AND REGULATION OF STEAM-BOILERS*

By C. J. King†

Generally speaking, the primary object of automatic combustion control of boilers is to maintain a uniformly constant steam pressure at the turbine throttle, regardless of changes in the station load.

To accomplish this, accurate means must be provided to govern the flow of heat to the boilers in order that their steam output may, from moment to moment, equal the changing demand for electrical energy caused by the variations in lighting, heating, traction, or industrial load.

Next to the above consideration, a good combustion control system must give to the boiler plant means of obtaining maximum combustion efficiency at all boiler ratings consistent with the quality of fuel being burned.

If uniformly good furnace efficiency is to be maintained over widely changing rates of steam generation, then means must be provided to control the ratio of fuel-air input to the furnace substantially constant throughout the entire steaming range of the boiler.

As a secondary requisite to the above requirement, an accurate, positive, and simple means of shading the fuel-air ratio from one value to another is necessary to compensate for such variables as the changing quality of fuel, slagging of tubes, and character of fuel bed; and, while these functions of the control may be made fully automatic, our experience shows that better operation results when this correction is left to manual adjustment.

The importance of load distribution from boiler to boiler and its relationship to combustion control are often completely overlooked by the power-plant engineer, but we have found this feature to be extremely important from an operating standpoint, and in this discussion we wish to stress the advantages and economics to be gained from a control equipment that gives reliable means of setting and checking the correlation of the various boiler units at a central point of operation.

*Presented October 4, 1932. Received for publication October 31, 1932.
†Smoot Engineering Corporation, New York.

Viewed from a technical standpoint, these features of a good combustion control system are quite necessary, but we must not overlook four other equally important characteristics of a control that have to do with the physical properties of the individual units or entire system. They are as follows:

1. *Reliability of Operation.* This is very broad, but if fully met by the control manufacturer, it gives to the plant a character of continuous operation that under all conditions becomes desirable and practical.

2. *Ability of Control Alone to Handle Radical or Sudden Changes in Load.* In the second case, a control always able to take the unexpected load bumps without resorting to hand operation, is frequently spoken of by operators familiar with Smoot control as one of the outstanding features of centralized control, and this attitude on the part of the operating engineer is not hard to understand when one stops to consider the constant thought the modern operator gives to continuity of service.

Illustrating this point, we might refer to the time when the Toronto power station suddenly dropped its share of the system load. Lowellville station was steaming twenty 600 horse-power boilers at the time on a complete Smoot control, and immediately picked up 25,000 kilowatts in addition to its normal load of 25,000 kilowatts. The 100 per cent. instantaneous increase in load was handled without resorting to any manual operation, and with only a slight drop in steam pressure.

Again at the station of the Brooklyn-Manhattan Transit Corporation, in Brooklyn, we have a striking example of this feature. This station carries all of the subway and traction load for Brooklyn, and has under complete control seventy-two 600 horse-power boilers. On Armistice Day each year, 50 per cent. of the entire system load is instantly dropped for two successive one-minute intervals. With this extreme change in load, the safety-valves never blow, and the steam pressure rises only some seven pounds in 200. This remarkable performance is due entirely to the instantaneous response of the entire number of boilers always maintained under complete automatic steam-pressure control.

3. *Ruggedness and Power Inherent in Design.* This feature will warrant close consideration by the plant designer as well as the

operator. Regulators frequently have to move very heavy parts, the friction of which often increases with changing conditions or the age of the plant, so it behooves the engineer to make sure that more than enough power is always provided in these cases.

The boiler-plant regulators should be built in keeping with their surroundings—ruggedness, meaning an absence of delicate parts; simplicity of design, making for ease of adjustment; power correctly applied to fit the nature of the job. These things collectively give long life to the regulators, and extremely low maintenance.

4. *Adaptability of the Man to the Equipment.* This embraces a rather psychological aspect of regulation, but nevertheless, has a real bearing on results.

If a boiler-room engineer fully understands the operation of the control, he does not fear to take full advantage of its many features of flexible operation. On the other hand, if he has only a sketchy understanding of its workings, and his own men are not capable of taking complete care of its maintenance, then he invariably distrusts its ability to produce results.

In Smoot control we have always striven to produce equipment of which the basic principles as well as the operating technique come within the comprehension of the test engineer, as well as of the practical boiler-room operator.

Having outlined all of the necessary characteristics of a good combustion control system, we will briefly describe the Smoot method of centralized boiler-plant regulation, and show how it completely fulfils the requirements previously enumerated.

In Smoot control of combustion, the master controller or steam-conversion device plays a most essential part, inasmuch as the proportioning of the various functions of the boiler and their responsiveness to load changes are controlled at this point. However, regardless of the master controller design, no system of control can be more effective than the combined result of each individual regulator action.

The hydraulically operated regulator used in the Smoot system is a fully developed standardized regulating machine, its greatest virtue being its inherent stability.

While *stability* is undoubtedly the most important of the four outstanding characteristics of this regulator, the other three—*sensi*

tiveness, speed, and *power,* are quite necessary attributes of a universal regulating machine.

Full control of each one of the four characteristics is available in the Smoot regulator, and any one of the features may be accentuated independently with regard to the others. For example, the regulator may be required to control directly with a throttle-valve the speed of a stoker engine. Here the inertia of the engine fly-wheel, the quick acceleration of the engine, and the heavy changes in load, at once demand a very rapid regulator and an extremely stable one.

A similar illustration is found in the conventional forced-draft turbine-driven fan to be regulated by its steam-valve or nozzle control. Regulating such a unit directly for combustion-chamber pressure requires, in addition to speed and stability, a marked degree of sensitiveness or accuracy.

Problems of control analogous to these can not be handled satisfactorily by the type of regulator with its stability derived through a reduction of its speed, or with a fast regulator which is not at the same time dead-beat in its response.

This outstanding feature of stability in the Smoot regulator allows any number of regulating units to be grouped together, and, whether the individual regulators be fast or slow, powerful or slight, the combined result will be an effective response to load changes; that is, a definite unified movement of the various regulators without overtravel and without hunting interference from one machine to another.

With full control of each regulator's stability, it becomes an easy matter to assign a separate machine for each element influencing boiler operation.

In doing this, each important boiler function, such as draft, combustion-chamber pressure, or fuel-feed speed, is controlled by the true regulating cause-and-effect method; that is, the regulator moves on a given change to produce a restoration of balance between the cause of the change and the effect of the regulator position in restoring the original balanced condition.

This is equivalent to saying that this type of regulator is not a position-relationship device, because the regulator stroke, responsive to a given pressure or load change, may be long or short, entirely dependent upon how much movement is required to restore the control pressure balance.

The Smoot regulator recognizes a balance only between what is called for and what it produces, and if one-tenth its travel produces the balance, the regulator stops at that point. However, if it requires nine-tenths of its travel to correct for the same change, the regulator continues to move that amount, always acting under the control of its unique stabilizing device, being checked in its final travel position only by the restoration of the original control pressure, volume, or speed balance.

In the Smoot combustion control system, diagrammatically illustrated in Fig. 1, each regulator or group of regulators of like kind

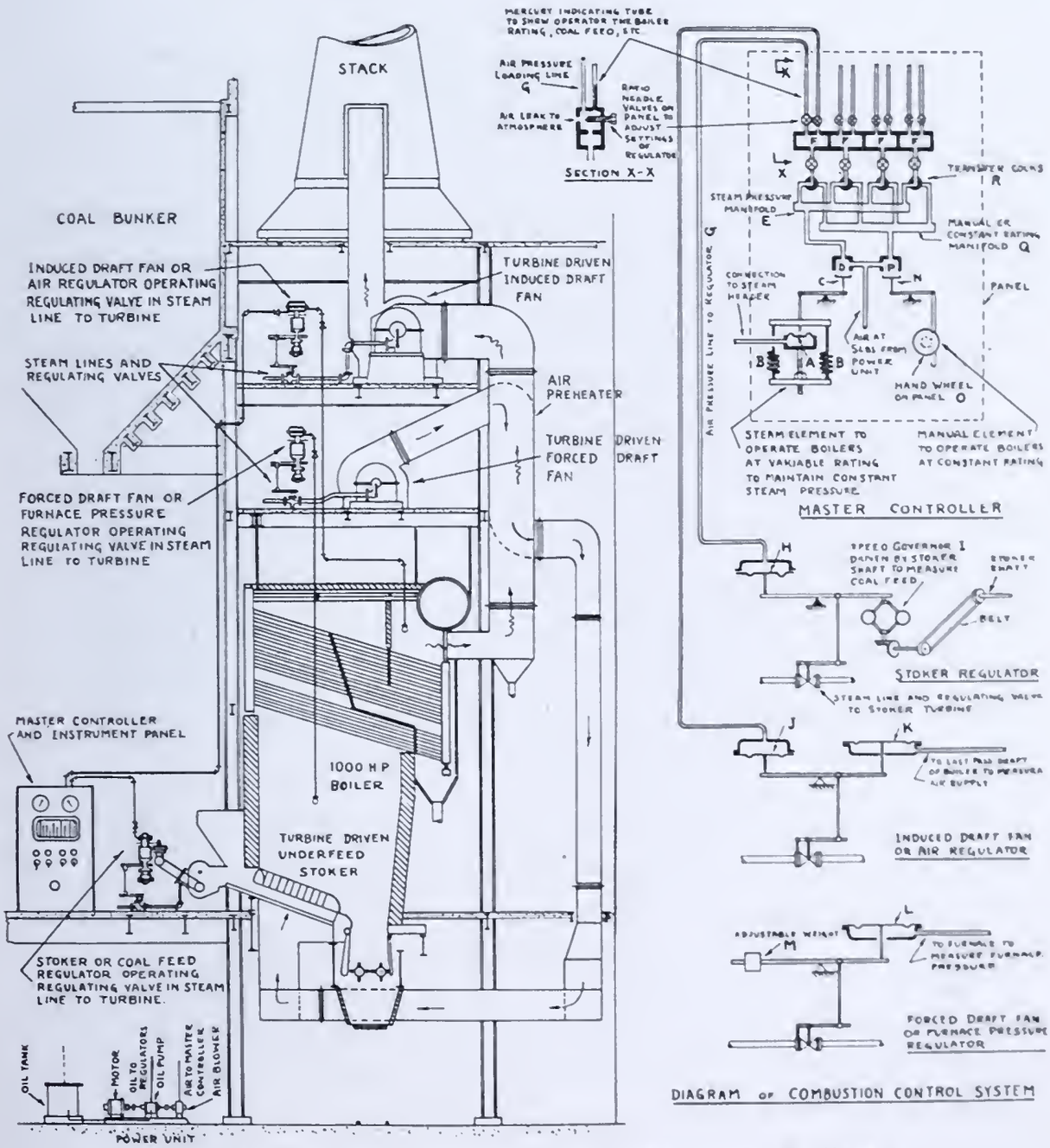

Fig. 1. Typical Application to Stoker-Fired Boilers.

controlling the inputs of fuel and air to the furnace are what we call master loaded. The master loading force on the regulator is obtained by using a small diaphragm which is supplied with a static air pressure dispatched from the master controller.

This master loading air pressure serves the same purpose as the adjustable spring or weight setting does on the conventional type of pressure-regulating valve, and the force from this diaphragm is balanced against the control force, but the regulator moves on a change in either the master loading pressure or the control force. Thus, the amount of the master loading pressure determines the value of the pressure, draft, or speed for which the regulator will control, as the case may be.

Low-pressure air, maximum five pounds, is used for the master loading because of its flexibility, cleanliness, and economy of piping and compression.

The master controller illustrated in Fig. 2 is so designed as to transform the station steam-header pressure changes inversely into air loading pressures dispatched through small pipes to the various groups of regulators. In this way the action of all of the essential regulators is synchronized and adjusted, as to their relative values one to another, at this centralized point of control.

Suitable indicating gages are provided as part of the master controller, being connected directly to the regulator side of each ratio-adjusting valve, so that as adjustment in the relationship of one combustion element to another is made, a visual indication of the amount of such adjustment is immediately shown. These ratio settings when once made remain fixed, and do not change unless reset by the operator.

Transfer devices are provided, through which the boiler regulators may be quickly thrown from automatic steam-pressure control onto manual operation at the master controller without making any individual regulator or ratio adjustments whatsoever.

After such transfer is made, the entire boiler output under control may remain at a fixed rating, or the boilers may be driven manually from a single hand-wheel adjustment for any desired rating within range of the auxiliary equipment.

In modern boiler rooms comprising large steam-generating units, it is becoming increasingly necessary to provide group control individual to each boiler.

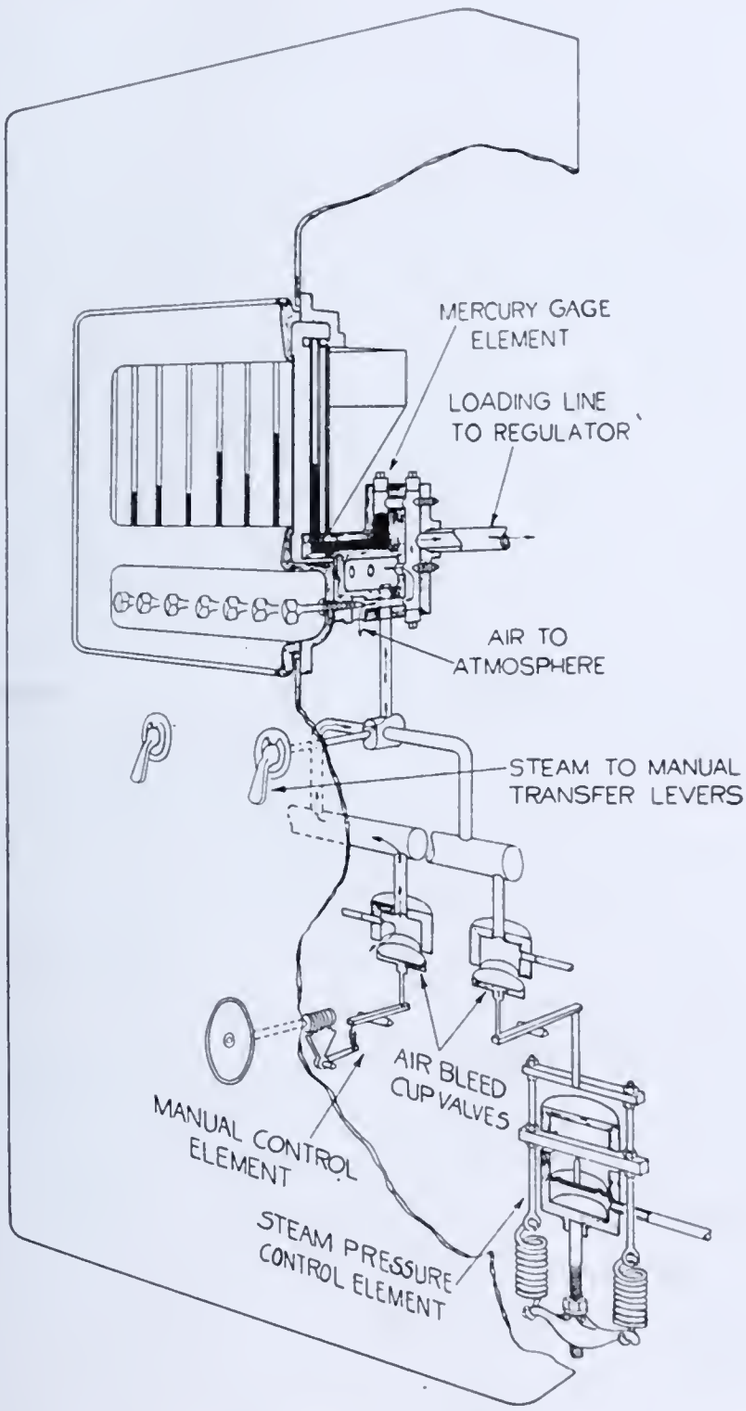

Fig. 2. Master Controller.

The separate boiler masters provided for this purpose are located adjacent to the boiler, and upon their steel panels are mounted all of the indicating and recording meters necessary to the operation of the boiler and the checking of its performance.

All of the various combustion functions of the furnace are under machine regulation, centralized at the boiler master. Provision is made then for connecting all of the boiler masters to a single station "supermaster."

When a boiler master for any operation or emergency reason is placed on manual control, as may be done either at the "supermaster" or at the boiler master, the boiler master regulators are still in control of the combustion functions of the furnace and continue to hold a steady combustion rate equal to any desired setting. This results in a regulated steaming output, automatically held constant at any predetermined value.

The "supermaster" provides relative adjustment of one boiler output to another, and incorporates the steam-air conversion element from which the individual boiler masters are automatically controlled for constant steam pressure. With this arrangement, any boiler master or number of boiler masters may be transferred at the "supermaster" to manual control at fixed rating, and the remaining boilers allowed to function automatically, taking the load changes and maintaining constant steam pressure.

Due to the wide variation in boiler-plant design and equipment, it is quite obvious that no one illustration can be shown which would give a complete picture of the many engineering features necessary to the general application of a modern combustion-control system.

However, Fig. 3 is typical of the simpler applications, and shows a boiler which is in continuous operation in a large Eastern central station with Smoot control, having a rated capacity of 400,000 pounds of steam per hour. The auxiliary equipment consists of vane-controlled induced-draft and forced-draft fans, with three-speed motors. Tangential firing from the four corners by four unit mills equipped with feeders operated by a motor-generator set constitutes the fuel-firing equipment.

Smoot control for this boiler comprises a boiler master and three regulators, one for the fuel feeder speed control of the motor-generator set, one for the control of the vanes of the induced-draft fan and one for the vanes of the forced-draft fan, giving, respectively, to the four units a complete control of the rating, fuel, air, and furnace draft.

Control installations similar to this are in continuous operation, where the individual boiler steaming rate runs as high as 1,250,000

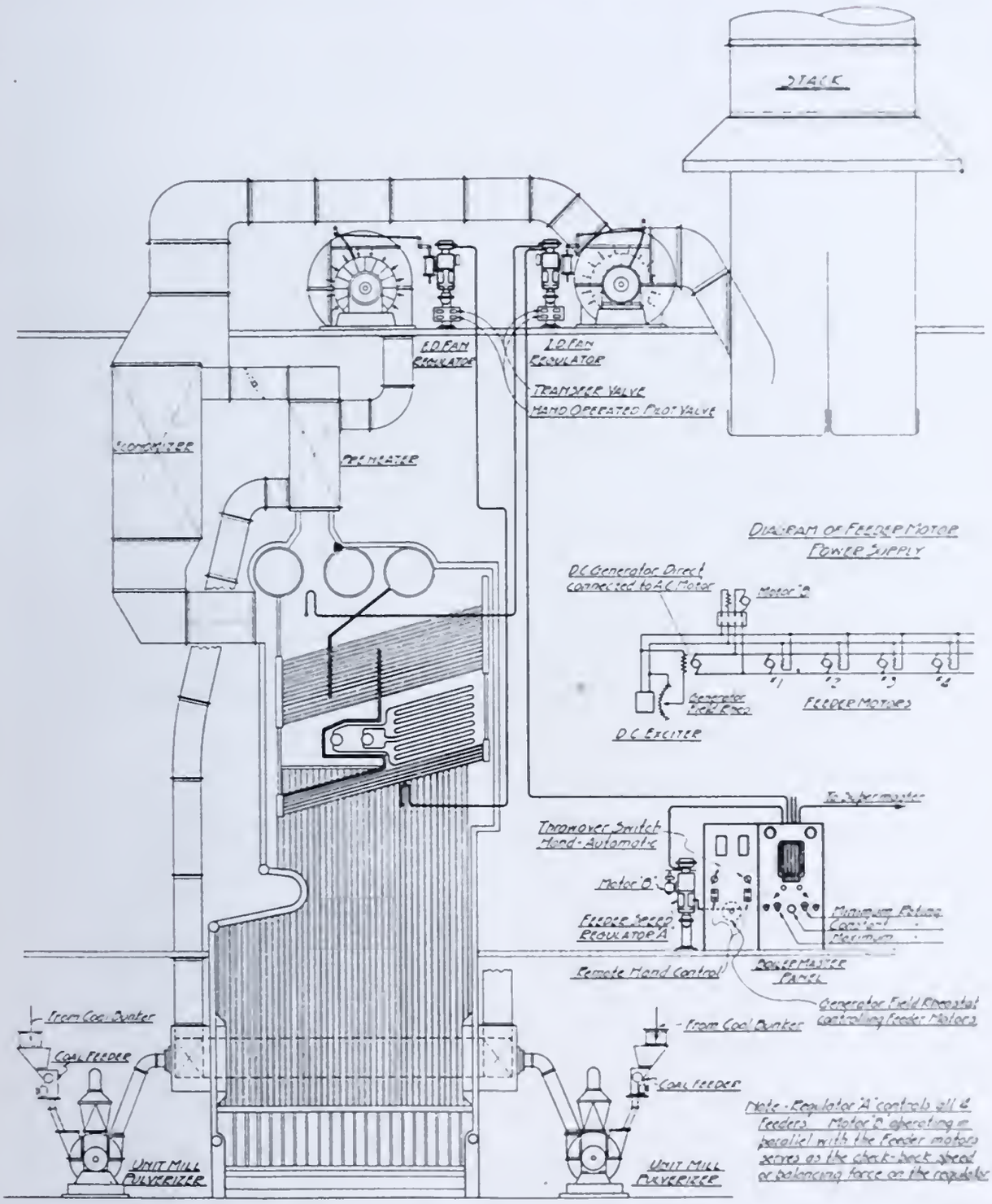

Fig. 3. Smoot Control Applied to Central-Station Boiler.

pounds of steam per hour. Here the application of control to the furnace air requirements varies from simple damper regulation on the primary air to the direct control of furnace draft by machine regulation operating multiple turbine nozzles on induced-draft-fan turbines upwards of 2000 horse-power each.

Large installations of this character are relatively new, and in most cases the engineering of the control equipment is seriously considered as an important part of the initial boiler plant design. This viewpoint is rapidly becoming more apparent to the design engineer as he realizes the operating and safety advantages that modern control equipment afford.

Now, when programs of increased economy are demanded, is the time to consider what results can be obtained by the proper use of fuel-saving and maintenance-reducing equipment applied to the older or less modern boiler plants.

As most of the older stations are equipped with some type of stoker-fired boilers, the following statements and conclusions are confined to this class of fuel-burning equipment. Many such plants are being run without any combustion control equipment, depending entirely on hand operation, and in a good many cases relatively good furnace efficiency is being obtained. Notwithstanding this fact, additional advantages directly due to control equipment are available, the value of which alone frequently justifies the installation of a good control system. These additional advantages are closely associated with the ability of the control to provide an equal distribution of load between the boilers.

Being able to distribute the boiler load accurately and continuously while the total steaming rate is varying, permits of a wider range of total available boiler rating. This feature is of equal advantage whether operating at low ratings or high ratings, as the spread in available range is increased both ways.

The greatest money gain to be made from equal boiler distribution and efficient operation at extreme low ratings is from the reduction of banked boiler losses.

With hand control it is necessary at periods of light load to bank quite a number of boilers, in order to be able to operate the remaining boilers at workable ratings. With Smoot control, however, boilers may continuously and economically be operated at ratings of 50 per cent. or less.

Being able to keep the boilers actively steaming with good fires at these low ratings permits a large reduction in the number of banked boiler hours. Stoker-fired boilers in the class being discussed frequently have quite a marked rising efficiency curve at low ratings,

which permits of additional gain or savings to be made from the ability to operate continuously in the reduced-rating range.

At the other extreme (high ratings) being able to obtain more total steam by having each boiler do its exact share of the total work frequently permits carrying the plant load with fewer boilers on the line.

This saving would not be available with hand control, due to the ever possible occurrence of suddenly increasing load demand. With a control sensing load variations almost before the steam-gage begins to move, there is no need to fear the results of sudden load increases as each boiler under control is instantly available and will respond with its maximum steaming rate.

Good fuel distribution and an accurate relationship between fuel and air are necessary to continued operation at light loads, and such operation pays dividends in the form of reduced combustible in the ash.

Frequently this item can be reduced as much as 50 per cent. as compared with hand-operating methods, due entirely to the accurate control of the fuel speed resulting in thinner, more flexible, and more efficient fires, which give almost completely burned out fuel on the tail-end of the stoker.

The ability of the entire control to function with complete stability at light loads permits the operator to take full advantage of this feature of reduced combustible in the ash.

To illustrate the difference between hand operation and Smoot control of a boiler room, with particular reference to boiler load distribution and banked boiler losses, refer to Fig. 4, which shows one day's typical hand operation of seven 750 horse-power underfeed-

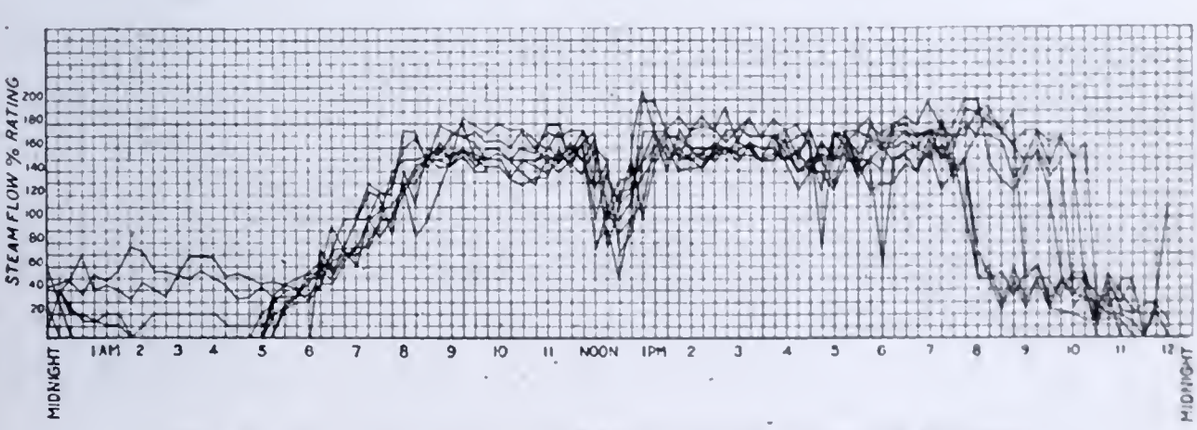

Fig. 4. Result of Typical Manual Operation of Boilers.

stoker-fired boilers, with steam flow plotted simultaneously against time.

This plant has an average industrial load, plus an extremely variable steel-mill load. The chart shows that frequently one boiler was rapidly increasing its rating, while another was dropping its load at about the same rate. This constitutes merely an exchange of load between the boilers, while the individual boiler charts would seem to show that the plant load was varying. It is only necesasry to study this performance slightly to visualize the fluctuations in boiler efficiency which occur when the boilers are driven independently from low ratings to high ratings with this type of operation.

Contrast with the above the actual boiler operation under Smoot control, as shown on the chart, Fig. 5. Note the almost perfect

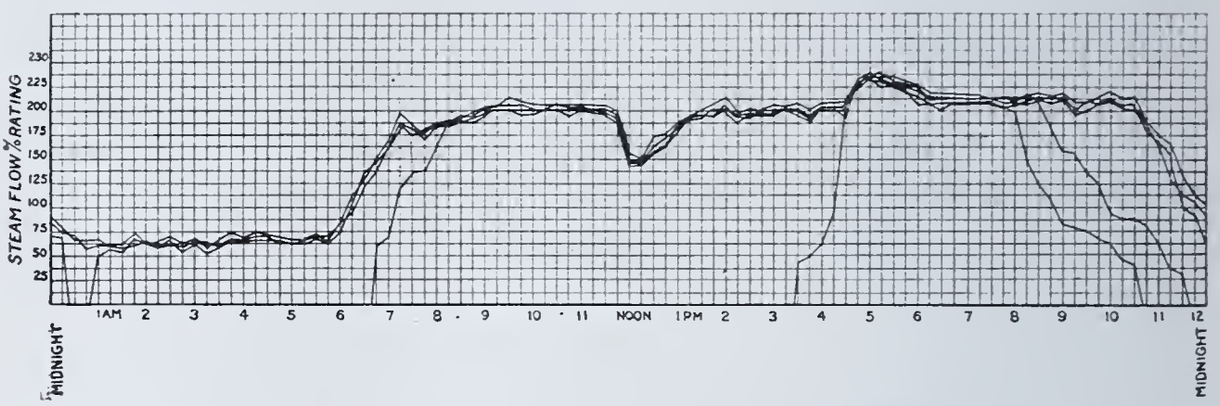

Fig. 5. Result of Mechanical Control of Boilers.

equalization of the relative boiler loads and how each boiler responds alike to the station steam demands. Also observe the accuracy with which controlled boilers can be brought from bank on to the line without appreciably disturbing the existing steaming boilers.

In bringing out these control features, we do not wish to depreciate in any way the more conventional advantages to be derived strictly from a combustion standpoint, but rather to emphasize those outstanding advantages of Smoot control, usually referred to as intangible assets.

The following summary is an average of the results in percentage of fuel savings to be expected from the foregoing outlined features, but does not include the more commonly stressed combustion figures due to better furnace efficiency.

1. More equal division of load among boilers..... ½ per cent.
2. Reduction of banked boiler losses.....1½ per cent.
3. Increase in boiler efficiency.....1½ per cent.
4. Reduction in combustible matter in ash..... ½ per cent.

Total savings .....4 per cent.

In utility plants where the steam generated is used in turbo-generators, another item of saving can be credited to the control (in comparison with hand operation) derived from better thermal efficiency as a result of being able to raise the turbine throttle pressure to a higher operating value. This gain is accomplished by maintaining the boiler pressure nearer the safety-valve setting than is possible by hand operation.

Approximately one per cent. for each 25-pound gain can be made in this way and in many cases, due to closer and more reliable control of the pressure, gains approximating ½ per cent. can be made.

The really intangible advantages of control not mentioned at all so far in this discussion are such points as ease and convenience of operation, the smoothing out of sudden load disturbances in operation, general plant betterment, and a decided improvement in feed-water distribution among the boilers. These points are rated by many experienced operators on a par with the value of fuel economy.

Generally speaking, the outstanding advantage of this type of control is that the supervision of combustion efficiency is centralized at the master control panel, where all of the important indicating and recording apparatus is grouped.

With Smoot control in charge of the boiler load distribution and automatic maintenance of steam pressure, the operator need not fear the consequences of sudden load fluctuations of radical nature, as the control quickly senses these changes and either makes the correction or is well on the way to finishing it before the operator is aware of the disturbance.

Tiresome and repetitive adjustments by the operators are replaced by untiring and accurate machine movements, co-ordinated in their action to produce continuous results justified by test operating conditions.

Results are not dependent upon the judgment of shift firemen, but become the responsibility of the trained combustion engineer or

boiler-room chief, whose modern set of operating control equipment relieves the fireman of the task of maintaining steam pressure, fan speeds, and making damper adjustments, etc., so that he may more effectively devote his time and attention to the fuel distribution, inspection of the boiler, or furnace conditions.

The precise adjustment and extreme ease with which modern large boilers, either stoker fired or powdered-fuel fired, can be controlled when the various functions are governed with true regulating machines, is a decided advantage. True regulating machines on the boiler are what the hydraulic governor is to the turbine, the safest, most dependable, and most rugged device in the power-plant. The mechanical hydraulic-type turbine governor is constantly called upon to do the steady job of making minor load corrections, but at the same time it must always be capable of handling full load swings.

These same basic principles of turbine regulation and design were originally inherent in the Smoot regulator, and still remain the foundation of our machine control.

In no small way do they contribute to the ease of operation and positive control so frequently stressed by the operating engineer experienced in the use of modern boiler regulation, and conversant with the advantages of Smoot control.

ELECTRICAL SYSTEM FOR METERED CONTROL OF BOILER FURNACES*

By E. S. Bristol† and B. F. Keene‡

Before entering into a discussion of any particular form of combustion control for boiler furnaces, it is only logical to outline briefly the major reasons for employing such equipment. These may be set forth as follows:

1. Increase in efficiency is probably the first point which comes to mind in considering the benefits which should result from the application of automatic control to a boiler plant. With an adequate automatic system, daily operating efficiencies will approach as an upper limit the test efficiency for the same load conditions. The character of the firing and draft equipment to be regulated will have an influence upon the closeness of the approach to the test value, but in general the difference will not exceed one per cent. and in many instances it is less. In plants operating without automatic control, the existing spread between operating efficiency and test efficiency gives a measure of the fuel savings which can be made by utilizing automatic equipment.

2. By taking over the performance of routine repetitive functions, automatic control relieves the operator of the greater part of his machine-like duties. There will thus follow an improvement in general boiler-room operation by virtue of the fact that the operator's intelligence can be directed to the functions actually requiring it. This situation will make the operator's job more interesting and will incline him to study out plans of bettering performance. In making this statement, it is assumed that the management will maintain the proper attitude of the operator to his job. Where it is not feasible to employ high-grade operators and encourage them to take an intelligent interest in their duties, automatic control will make it possible to maintain much improved results over manual control when employing a lower grade of operators with a minimum of supervision.

3. Automatic control is of considerable benefit in showing up improper conditions of boiler equipment before they would otherwise

*Presented October 4, 1932. Received for publication November 4, 1932.
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be noticed. With control in service, the boilers are held to a standard performance; if a deviation develops it is an indication of trouble. Dropping out of baffle bricks, improper feed-water regulation, etc., have been definitely brought to attention in this way.

4. Automatic control equipment has a very real value at times of plant emergency, such as loss or sudden increase of load, or tripping out of a generator. Under such conditions the control functions smoothly and immediately to make the necessary readjustments of the regulated elements at all boilers. The operators are thus relieved of the necessity of trying to change at once and by the right amount all the draft and fuel settings, and are probably saved from making a number of false moves in the attempt. With the control functioning to meet the changed condition properly, the operators have a brief respite to consider what steps (if any) they need to take.

While there are other advantages to warrant the use of automatic control, those cited above constitute the major reasons. The extent to which these advantages are realized is naturally dependent upon the type of regulating equipment employed. Modern combustion control systems can be divided into two general types—position control systems and metered control systems. The former type acts to move the regulated elements to predetermined positions in response to the action of a master controller responsive to load demand. With such a system, the various power elements which act upon dampers, etc., all move by predetermined amounts for a given impulse from the master controller. To translate these fixed, predetermined movements into correct adjustments of draft and fuel supplies, the various damper, valve, and rheostat linkages must be laid out for the proper co-ordination of all the various factors over the full control range; as an alternative, the power elements themselves may be provided with cams or equivalent means for arriving at the necessary position relationships when using simple and direct linkages. The distinctive feature of the position control system is that the regulating elements all move to calibrated positions for each setting of the master control mechanism. The character of the result obtained is dependent upon the extent to which operating conditions depart from the standard conditions for which the calibrated relation is set up, and upon the accuracy and frequency with which manual readjustments are made to offset the effect of such departures.

The metered combustion control system functions to maintain a definite relation between load demand acting upon the master controller and the rates of supply of fuel and air. Each auxiliary controller measures a force representative of the quantity it regulates and moves the damper, valve or other element until the value of that force corresponds with the load demand as transmitted through the master controller. Thus the adjustment of the regulated device is independent of position setting of dampers, valves, etc. The distinctive characteristic of the metered system is that each controlled quantity or rate is measured and is adjusted until its measured value corresponds with the established requirement. Such a system is naturally capable of correcting for a number of variables that serve to upset the draft and fuel relations which would be maintained by a position type of system.

Some commercial systems employ a combination of metered and position control. In particular, no modern system depends upon position control for maintaining desired furnace pressure in furnaces equipped with forced draft, this element being of such importance from a safety standpoint that a metering type control is always employed. The equipment required to provide metered response of fuel and draft to load changes is somewhat more expensive than that providing position response, so that the position type control is the one generally used on small boilers, up to, say, 400 rated horse-power. In applying control to larger units, it is generally considered that the metered type control is worth the additional price.

The scope of this paper is limited to the consideration of an electrical type of metered combustion control and to the presentation of the particular advantages which the use of electricity makes it possible to secure in this type of system.

An important advantage of electricity as a control medium is the ease with which it lends itself to the use of simple relay devices, whereby small forces obtained from sensitive measuring elements can be used to regulate the application of the larger forces necessary for controlling heavy power-plant equipment. Electrical relay devices are inherently free from frictional elements, such as stuffing-boxes, which must be considered in the design of hydraulic and compressed-air regulators. As a result of this absence of friction, the elements performing the metering function are highly accurate and sensitive and

will maintain these favorable characteristics without the necessity of frequent attention to the mechanism of the regulator. The metering elements of electrical combustion control systems will commonly be found smaller than those of hydraulic or pneumatic controllers employed for similar purposes.

Probably the chief characteristic which has led to the universal use of electricity for control systems of all sorts is its flexibility. It is a simple matter to provide switches for a number of different control combinations when using the same electrical units. Thus, electrical systems provide full automatic control, semi-automatic control for individual boilers, and push-button control, with no appreciable additional equipment. Transfer valves, etc., are employed to provide similar results in systems employing fluid mediums, and in some cases electrical equipment is added to such systems to obtain push-button control. Electrical control can be readily tied in to the system of interlocks for the boiler auxiliaries, making it necessary for the induced-draft fan to be running and the outlet damper open before fuel feed can be started. Such interlock requirements can be easily met and where an auxiliary (such as a pulverizing mill) can be transferred from one boiler to another, automatic control and the proper sequence of interlocks can still be maintained through the use of transfer switches.

Ease of installation is a point in favor of electrical control. It is necessary to run only a single conduit to each unit of the system to carry all of the conductors required to meet complete control requirements. The elements of the system can be located in the most convenient places for the particular function of each—metering, power application, or manual operation, as the case may be. It is not necessary to choose compromise locations because of any necessity for maintaining intimate mechanical relations of the regulating and power elements.

A very important advantage of electrical control to the operating man is its inherent stability of setting. The power elements commonly employed in such systems consist of irreversible reduction gears with electric-driving motors. Unbalanced dampers have no effect in producing drift of the control in the intervals between impulses from the regulators. Further, but more important, failure of power supply (corresponding to failure of power fluid in hydraulic or pneumatic

systems) does not leave the various dampers free to drift one way or the other depending upon the particular unbalance of forces to which they may be subjected. Everything stays put under such conditions until the operator himself makes intentional corrections. There is no tendency for the control to run wild and move everything to a limit under failure of power supply.

Another feature of the electrical control system under discussion, which is of considerable importance from the standpoint of maintenance, is the ease with which the few moving parts of the controllers can be inspected and, when necessary, repaired. There are relatively few moving parts in the well designed electrical system and in the majority of cases these are so located that their operation can be observed through inspection windows. When necessary, inspection doors or covers make them accessible for attention. In few instances is it necessary to take the control out of service to make any required adjustments of these parts. Furthermore, the accessibility of the moving parts of an electrical control system obviously reduces the time required for maintenance.

While other advantages of the particular electrical control system under consideration could be enumerated, such a discussion would resolve itself into a direct comparison with systems of other manufacturers now on the market. Such a comparison would serve no useful purpose in this meeting; we might better illustrate a few of the advantages by considering a typical application of an electric-metered control system. A pulverized-fuel-fired plant is considered, but stoker, oil, gas, or combination-fuel-fired boiler plants present similar problems.

Consider a boiler plant consisting of a number of boilers with auxiliary equipment as indicated in the schematic diagram. Each boiler is fired with pulverized fuel by two constant-speed unit mills with variable-speed, direct-current, motor-driven feeders. Forced and induced draft are supplied at each boiler by multi-speed motor-driven fans. Close regulation of draft is obtained by means of dampers—one in the boiler uptake and one in the forced-draft supply duct. With this general arrangement, the principle of operation of a suitable control would involve establishing a loading force or control current proportional to load demand by means of a rheostat actuated by steam pressure and termed a "master controller." This control current, after pass-

ing through master panel equipment consisting primarily of a selector switch, combustion rate rheostat and a total load indicator, goes to a master control bus. The control circuits for each boiler are tapped from this bus, the circuits being in parallel, while the individual controllers at each boiler are in series electrically. The control current for an individual boiler passes through the individual selector switch, combustion rate rheostat, combustion rate or boiler load indicator, the fuel-air ratio rheostat and the coils of the air-flow controller. If furnace suction is to be maintained at values increasing slightly with rating, the control current also flows through the coils of the furnace pressure controller.

Considering first the air-flow controller, we find a balance consisting of a beam pivoted on a knife-edge. Two pressure bells mounted on this beam are sealed in oil and are subjected to a force or draft differential taken across a section of the boiler. This force is a measure of the flow of air or gases through the boiler and varies as the square of the flow. Also mounted on a vertical arm of this beam is a coil which is free to move between two fixed coils whenever the beam moves. The control current flows through these three coils in series and sets up a force at the movable coil dependent upon the strength of the current or load demand. This force actually varies as the square of the current and opposes the force due to air or gas flow. The squares cancel and we have a direct proportionality between actual air or gas flow and control current or required air flow. Any unbalance between the forces causes an unbalance at the controller and a consequent readjustment of the air flow through the boiler to restore controller equilibrium. The primary element regulated is the uptake damper with fan speed switches mounted on the drive unit to make required adjustments of the speed of the induced-draft fan to keep the damper within its normal operating range. Acting in conjunction with its draft control, a furnace pressure controller functions in a manner similar to the air-flow controller to maintain furnace pressure at a predetermined constant value. This controller regulates the forced-draft damper and forced-draft fan in parallel.

The operation of the air-flow controller (and incidentally of all metering controllers) is analogous to the beam-type grocer's scales. Just as the commodity being weighed by the grocer is balanced against a known weight, air supply is balanced against the control current

representative of air demand. Thus it is evident that electrical metering control resolves itself into a simple weighing problem.

The same control current flowing through the coils of the air-flow controller also flows through an adjustable resistance termed a fuel-air ratio rheostat. The voltage drop taken across this resistance varies with the strength of the control current, is a measure of that current, and represents the fuel demand. Attached to each mill feeder is an electric tachometer setting up a voltage dependent upon the speed of operation of the feeder. When two or more tachometers are connected in series electrically, the total voltage is a measure of the average feeder speed. The tachometer and fuel-air ratio rheostat voltages oppose each other and any voltage unbalance is measured by the fuel feed controller. This controller regulates the feeder motor gang rheostat to maintain a definite relation between control current and speed of the feeder.

Since both air flow and speed of the feeder are held in definite relation to a common control current, they bear a definite relation to each other. By changing the setting of the fuel-air ratio rheostat, the fuel-air relation can be changed as desired. Under some circumstances the adjustment of the ratio rheostat is accomplished automatically by means of a CO_2 recorder-controller. This controller uses the CO_2 content of the flue-gases as an index of combustion efficiency and makes the required adjustment of the ratio rheostat to maintain CO_2 at a predetermined constant value, thus correcting for changes in B.t.u. value, moisture content, etc , of the coal, and for irregular feeder action.

With the control system just described and the particular apparatus employed in the system, there are many advantages worthy of consideration. Some of these advantages were mentioned earlier in this paper. Let us now give further consideration to these points.

1. Efficiency

a. By metering the supplies of fuel and air, the most efficient combustion conditions compatible with plant lay-out and load requirements will be obtained.

b. Efficiency of combustion is maintained regardless of momentary variations in individual boiler output which may be due to variations in feed-water temperature, etc.

c. The rate of combustion is maintained and is not sacrificed to efficiency of combustion at times of irregular B.t.u. supply. Under such conditions the quantity in error, the fuel feed, is adjusted manually or automatically—depending upon the particular plant lay-out —through the fuel-air ratio rheostat. This rheostat permits of a wide range of adjustment of the ratio between fuel and air supplies as required.

d. Efficient operation over wide ranges of rating is made possible by the direct proportionality between the speed of the feeder and control current.

e. The fact that repetitive adjustments of fuel and draft are made automatically, leaves the fireman more time for those supervisory duties which tend to improve overall plant performance.

f. The ability of the control to show up improper conditions can be thoroughly brought out only by a more lengthy description than time will permit. As a brief illustration, if baffle leakage develops, the heat transfer to the boiler will have a different value for a given electric control current. Under normal conditions there is a definite relation between control current and output of boiler steam. Changed baffle conditions affecting heat transfer will disturb the normal relation between steam output and current, so that the affected boiler will have a different output from companion boilers operating on control. Other variations from normal conditions will similarly result in deviations in boiler output from standard, and will serve as a warning of impending trouble.

2. Reliability

a. Regardless of the perfection attained in the theoretical design of a control, unless the apparatus going to make up the system is properly designed the control will have little practical value. This factor has been emphasized most fully in the design of the electrically operated metered control under consideration.

b. From the standpoint of apparatus, it has been pointed out previously that the controllers are comparable to grocer's scales in principle. Nevertheless, the high accuracy and sensitivity so essential for satisfactory performance have been built into each instrument. Take, for instance, the furnace pressure controller. This controller

is a sturdy machine, yet one which can be so adjusted that a change of a few thousandths of an inch of water will unbalance the controller and close an electric contact carrying a very low current of the order of hundredths of an ampere. This current, in turn, is sufficient to energize the relay coil and close the contacts in the circuit of the motor forming a part of the forced-draft damper-drive unit. Thus by simple electrical means the change in draft of 0.002 to 0.003 inch of water can be magnified into a force of hundreds, or, if necessary, thousands of pounds to adjust the damper.

c. Probably one of the most important features of a control system is the degree of protection (the guarantee of safe operation) attainable with the control. Electrical control leads in this field because of the ease with which interlocks, alarms, etc., can be incorporated therein. Such interlocks are not so easily accomplished by mechanical means. Each particular plant lay-out presents its own interlock problems. Some of the more common interlocks will be briefly outlined.

Sequence interlocks provide for the proper starting of boiler auxiliaries and for tripping them out of service at times of failure of, say, the induced-draft fan motor.

Failure of the loading or control circuit at a boiler would cause all drive units to remain stationary, and would sound an alarm to call the attention of the operator to the trouble. An annunciator would indicate the particular boiler on which the trouble had occurred, and there would be no tendency of drive units to go to extremes of travel and shut boilers down, thereby dropping the load or opening the boilers up wide and blowing safety-valves. Neither would there be a tendency for the draft and fuel to drift into an undesirable or even explosive condition.

Fuel and draft are so interlocked that when the draft is at a maximum, fuel can not be increased, and when fuel is at a minimum the draft can not be decreased. This also definitely avoids the possibility of dangerous operating conditions.

Fuel and draft control are so designed that an excess of air is always provided for major load changes. Thus for an increase in rating, the air is increased more rapidly than the fuel, and for a decrease in rating the air is decreased more slowly than the fuel.

3. Flexibility

a. The flexibility obtainable through the use of electricity as a control and power medium is well known to industry. It is no exception when used for this purpose in the control of combustion.

b. As indicated in Fig. 1 and 2, the use of electricity makes it possible to locate the control devices where most convenient—the

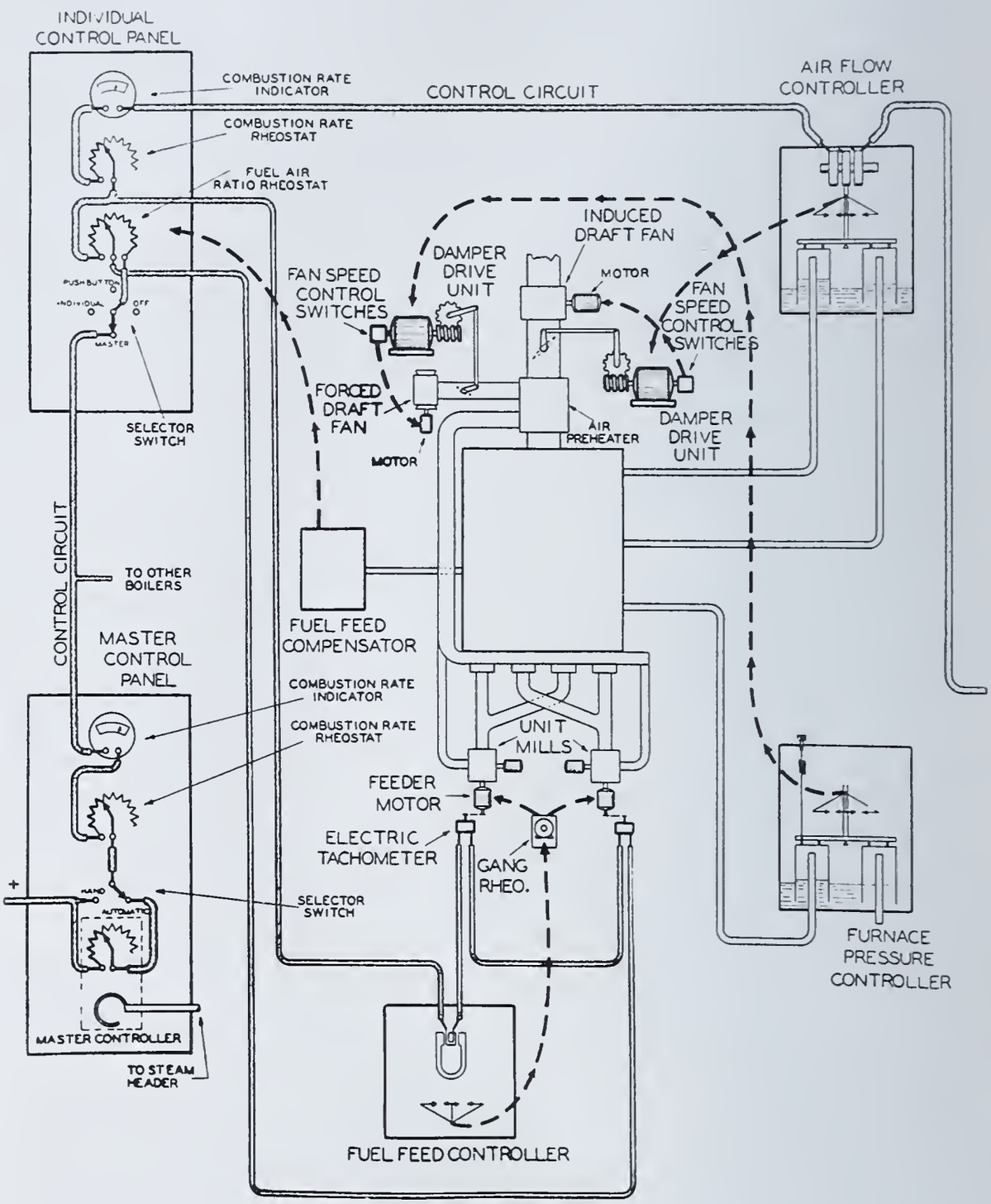

Fig. 1. Schematic Lay-Out of Leeds & Northrup Company Metered Combustion Control for Pulverized-Fuel-Fired Boiler.

drive units at their respective devices to be regulated, the controllers grouped at a convenient location, and the push-button stations, switches, etc., at a suitable central-control point for each boiler or group of boilers.

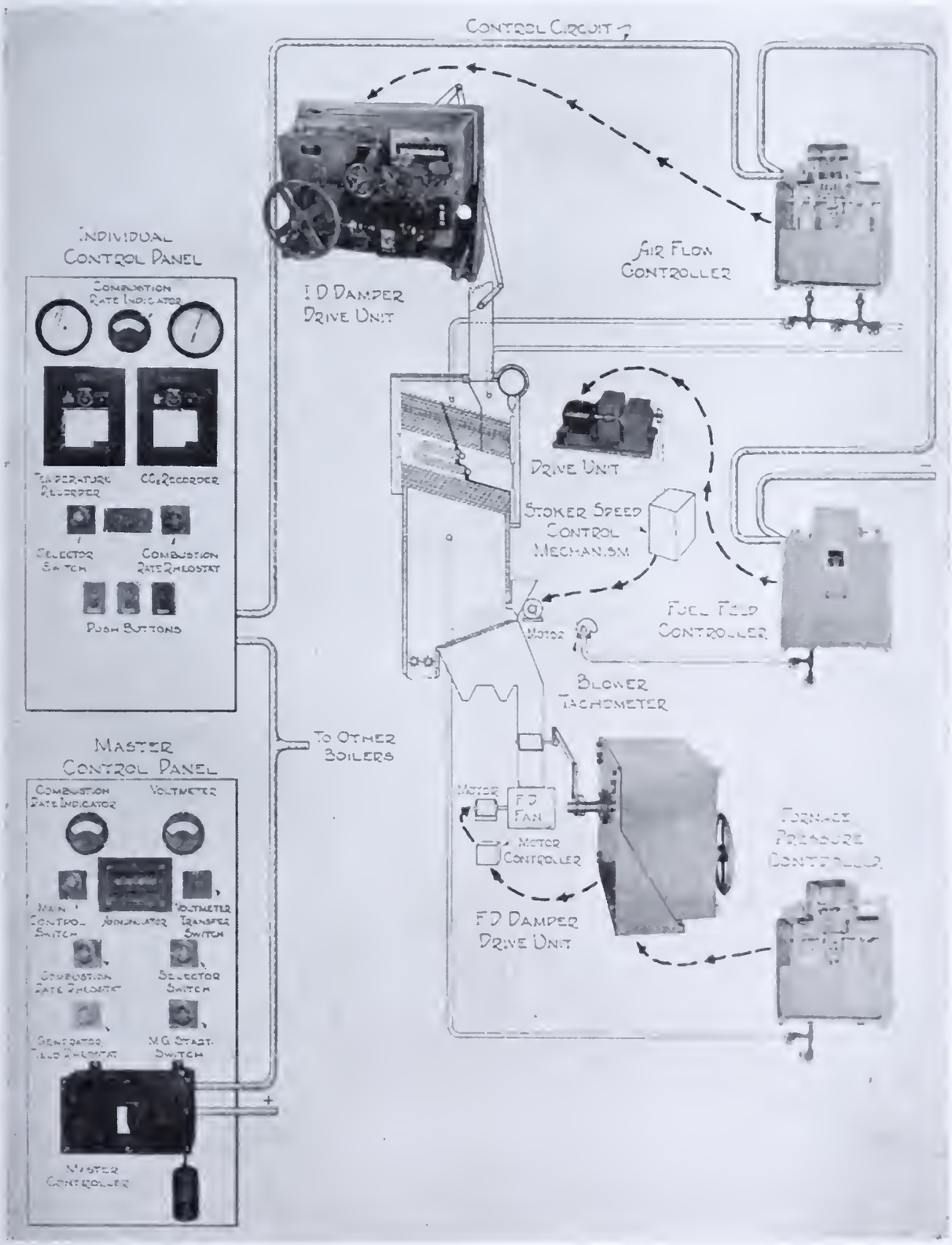

Fig. 2. Schematic Lay-Out of Leeds & Northrup Company Metered Combustion Control for Stoker-Fired Boiler.

c. The switching arrangement at each boiler makes it possible to change quickly and readily from one type of control to another, three operating positions being available. "Full automatic" position provides correct fuel-air ratio and supplies of fuel and air in proportion to the load demand; "individual automatic" provides correct fuel-air ratio, but the combustion rate is dependent upon the manual setting of a combustion-rate rheostat; "push-button" provides remote centralized but segregated control of dampers, rheostats, etc. An "off" position of the selector switch disconnects the control electrically and makes manual operation of dampers, etc., possible.

d. By the proper use of the individual selector switch and combustion-rate rheostat, the load may be distributed equally among the boilers or in any ratio required by operating conditions. Further, as previously indicated, one or more boilers may be operated at constant ratings while the other boilers take the load swings.

While other features of electric control might be brought out, we believe sufficient emphasis has been placed on its major points of advantage. We might summarize by stating that such a system can be briefly characterized as being efficient, reliable, flexible, sturdy, and simple.

DISCUSSION

L. Tattersall:* Automatic combustion control equipment is generally accepted as a necessity in large power-stations. It does to some extent improve the efficiency and relieve the operators from many of their machine-like duties.

Automatic combustion control however should not only relieve the operators from performing mechanical functions but should be so reliable and exact in its operation that the number of boiler operators may be reduced when other plant conditions permit.

There is installed at the James H. Reed power-station of the Duquesne Light Company an electrical control system as described by the authors. The station has one 60,000-kilowatt unit and three boilers. Each boiler has a single underfeed stoker, two forced-draft fans and two induced-draft fans. The fans are constant speed in two steps

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with dampers to control air flow. Dampers are driven by motors through reduction gears. The stoker is driven by a constant-speed motor through a Waterbury hydraulic variable-speed transmission. This stoker drive is ideal from the standpoint of applying automatic combustion control, in that stoker speed can be varied by small increments over the full range from standstill to top speed. The control impulses from the master controller are applied to the motors driving the induced-draft dampers, the forced-draft dampers, and the hydraulic transmission speed changer.

Our experience with this system as installed does confirm some of the advantages presented by the authors. The operator can change very quickly from automatic to push-button control and does so whenever occasion demands; he can again return to automatic control all within a few seconds. The elements of the control system are sensitive and remain so with relatively little attention. Such operating adjustments as are required from time to time are made easily and quickly without taking the control out of service. The dampers and speed-changing devices under automatic control do remain stable in their positions when the system fails to function. This is of real importance for it prevents radical changes from orderly operation which would occur should the dampers and speed-changing devices take up extreme positions suddenly on failure of the control equipment.

The control system, however, is not perfect. Stoker speed control is affected by many variables. Because of the number of variables which affect stoker speed control it is rather unlikely that automatic control can be developed to substitute in every respect for human judgment in controlling stoker speed. Our experiences, nevertheless, show that automatic regulation assisted by manual regulation is easier and better than when only manual regulation is employed.

During periods when sudden changes in load take place our experience has been that load decreases are handled better than load increases. This appears to be due to the characteristics of the combustion equipment and the step by step nature of the control. The control system under discussion has been designed to effect faster damper opening when the pressure drop is large than when the pressure drop is small. Attempts have been made to speed up the damper action by increasing the frequency and length of impulses by the con-

troller but this has resulted in unfavorable regulation due to hunting of the controls.

The authors refer to unbalance of dampers as having no undesirable effects on the performance of the control equipment. By experience we find it quite necessary that dampers be well balanced. It appears logical that motor-controlled elements such as dampers or speed-changing devices must have approximately equal resistance to movement in either direction. When unbalance exists, each impulse will tend to drive the motor faster and farther when operating in the direction corresponding to the lightest load on the motor.

B. F. Keene: The discussion on the combustion control installed at the James H. Reed station presents an operating viewpoint of this type of apparatus and includes several items which should be of interest to all. From the information offered, it is evident that the installed control is of practical advantage under the conditions for which it was designed. It has incorporated therein those features to make it a useful and efficient tool in a boiler room. While the control operation reported under sudden load changes is not as smooth as can be desired, a recent investigation indicates that relatively minor changes in the control can be made to improve this condition. It should be borne in mind that each control system is designed and adjusted to handle normal plant conditions with the best results and at the same time to give reasonably satisfactory service under abnormal conditions. For this plant, the control is adjusted for base load conditions as normal operation and for a rapidly swinging load as abnormal operation.

It is not felt that there is any significant difference in the type of boiler response resulting from the use of an interrupted action as compared with a continuous action in following major load changes, provided that the adjustments give the correct overall rate of change in combustion rate. In any practical application the rate of control action must be set so as to take account of the natural rate of response of the controlled equipment. Lag of draft and firing equipment, and relation of boiler heat storage to output, all have an effect upon the performance which can be obtained from the control system. There is no limitation presented by the electrical type of control which prevents the overall rate of response from being adjusted to meet any particular combination of variables.

In referring to damper unbalance, I believe that the statement in our paper was misunderstood. Our intention was to point out that the irreversible worm-gearing of a motor-drive unit serves to lock a damper in place except when movement is actually called for by the automatic control action or a push-button impulse. There is no possibility that an unbalanced damper can shift its position by itself, thereby causing the drive unit to rotate. It is realized that approximate balance may be of some importance as affecting the relative rates of damper travel when opening and closing.

Along the lines mentioned by one of the gentlemen this afternoon, it may be of interest to present some definite service figures on control as taken from actual records from utility and industrial plants using systems of the type described in our paper.

Number of boilers	Type of firing	Outage
3	Pulverized-coal unit system	0.2 per cent.
4	Underfeed stokers	0.9 per cent.
2	Gas	0.3 per cent.

The above figures show that suitable combustion control equipment compares favorably in actual service with other types of power-plant equipment.

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AUTOMATIC CONTROL OF COMBUSTION*

H. M. Hammond†

Automatic combustion control is usually installed in a boiler plant in order to effect a saving of fuel through more efficient operation. This saving alone has, in numerous cases, more than paid for the initial cost of the control during the first few months of service. In addition to the fuel saving, however, there is usually a considerable saving in the cost of labor, because the number of boiler-room employees may be reduced.

The increase in efficiency resulting from the installation of automatic control is, in most cases, also accompanied by increased capacity, thereby postponing or eliminating the necessity for enlarging the power-plant. This reduction in overhead should be credited to the control equipment.

Automatic control has made it possible to operate boilers economically and safely over long periods of time, reducing the outage and improving the general character of the service. This factor has been of extreme importance in the central-station field where continuity of service is so essential.

The power-plants being erected by the leading central stations and the larger industrial concerns to-day are designed to operate as economically as possible, consistent with continuity of service. Many of the new stations are being designed with boilers to operate at 1300 or 1400 pounds pressure, and to be equipped with pulverized-coal-burning equipment, water-cooled furnace walls and other expensive equipment which will permit operating at maximum efficiency with high steam pressures, high steam temperatures, and a minimum of excess air for combustion. In order to realize on this investment it is essential that the equipment be operated under the conditions for which it is designed. In other words, if the most economical results and a good return on the money invested are to be obtained, a boiler designed for 1400 pounds pressure should be operated at 1400 pounds; a turbine designed for steam at 750 degrees should be supplied with steam at that temperature; and the water-cooled furnace walls with refractory-faced blocks designed for 20 per cent. excess air at all boiler rat-

*Presented October 4, 1932. Received for publication November 3, 1932.
†Bailey Meter Co., Cleveland.

ings should be operated with approximately 20 per cent. excess air.

It is practically impossible for a fireman in a large boiler plant to watch all of the indicating and recording instruments that show the conditions in the boiler, and make the frequent adjustments in fuel feed, induced draft, forced draft, and rate of feed-water flow, which are necessary to maintain the desired steam pressure, the proper air supply and water-level for best results. This is especially true in cases where the character of the fuel may be continually changing, the air temperatures may not be uniform, and the load on the boiler may be fluctuating through wide ranges. It has, therefore, been found advisable, and in fact necessary, to use automatic control if best results are to be obtained. Automatic control equipment which has been properly designed will continuously maintain the proper relation between the various factors and instantly correct conditions for varying steam demands.

The primary function of any combustion control system is to supply fuel and air to the boilers in proportion to the demand for steam. In the better types of control this is accomplished by changing at some suitable point in the system the rate of supply of both fuel and air simultaneously in accordance with the demand for steam as indicated by changes in the steam pressure.

Most power-plant engineers realize that the steam pressure can not be maintained absolutely in accordance with the requirements at all times. It is desirable, however, to hold the steam pressure within fairly close limits in order to maintain maximum efficiency of the turbine or other prime mover.

In designing and applying automatic combustion control, consideration must be given to the time lag in combustion and heat transfer. If a small variation in steam pressure actuates the control to change the quantity of fuel and air being supplied to the boiler furnace, a further change in pressure may occur before the increased fuel and air supply will have had time to bring the steam pressure back to normal. It is, therefore, desirable to design the control equipment so that changes in the fuel and air supply will be made in accordance with the *rate* of change of pressure rather than by the deviation of pressure from the standard. In order to obtain the best results in regulating combustion, the method of control should be such that a change in boiler pressure will be stopped as quickly as possible and

the pressure brought back to normal at a rate which will not cause it to pass beyond the standard; otherwise hunting will take place.

In order to overcome pressure variations due to a rapidly fluctuating load, and yet not be affected by the time lag referred to, certain types of combustion control have been designed not only to make changes in the fuel and air supply proportional to the variations in pressure from standard and the rate at which the pressure is changing; but in addition (as soon as the control has succeeded in stopping the pressure change from normal and has started it towards standard) to change the rate of fuel and air supply in the opposite direction so as to check any rapid drifting back to neutral which would tend to cause the pressure to swing beyond normal in the opposite direction.

Those familiar with the operation of boilers and combustion systems will realize how closely a first-class boiler operator follows this procedure in controlling steam pressure. The operator knows that when a rapid drop in steam pressure takes place he must make extensive changes in the supply of fuel and air in order to check this pressure change, and he knows that, when he has succeeded in stopping the pressure change and it begins to return to the normal pressure, he must cut down slightly on the rate of supply of fuel and air, or else the pressure will swing beyond normal in the opposite direction.

Steam pressure can be maintained by the supply of fuel and air regardless of combustion efficiency or good heat absorption, but the best combustion efficiency is brought about only when completely burning the fuel with a minimum of excess air, creating a high heat potential or high furnace temperature so as to get good and complete transfer of heat from the gases to the water in the boiler and economizer. If this is not accomplished, fuel will be wasted, since an excess of air will cause loss of heat to the stack, while a deficiency of air will result in a loss of unburned gas and carbon. The second problem of control, therefore, is to govern the relationship between the fuel and air in order to maintain the most efficient combustion.

It is impossible to design a parallel system of control which will regulate the fuel and air in such a manner that the quantity of air being supplied will always, without readjustment, bear the correct relation to the quantity of fuel supplied. The quantity of air supplied for a given damper position or a given speed of fan will vary with changing atmospheric and temperature conditions. There are

also many factors in connection with the supply of coal which tend to complicate the problem of maintaining a predetermined ratio between the fuel and air without continual readjustment. With many types of pulverized-coal feeders, the height of coal in the bin, the percentage of moisture in the coal, and the fineness of the coal frequently cause a very wide variation in the rate of feed for a given speed of feeder. It is also obvious that a wide variation in heating value may exist for the same quantity of coal on the basis of either volume or weight.

In the case of stoker-fired boilers, if the hoppers are kept properly filled and there is nothing to interfere with the flow of coal to the feeding mechanism, the volume of coal may bear a fairly close relation to the speed of the stoker. There are variations in the quality of the coal, however, which make it impossible to maintain a good ratio of air to fuel by simply establishing a definite relation between the speed of the stoker and the weight of air supplied for combustion.

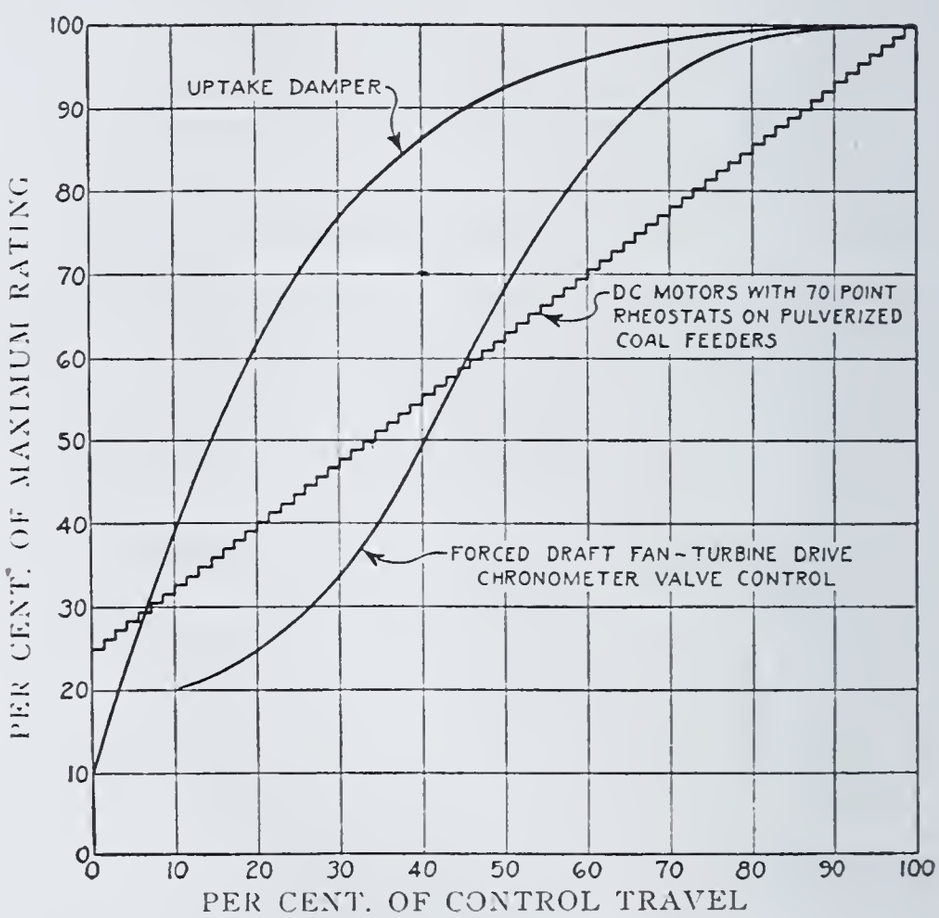

Fig. 1. Characteristic Control Curves.

Characteristic control curves of induced draft, forced draft and rate of fuel feed in terms of boiler rating plotted as a function of control position for a pulverized-coal-fired boiler, are shown in Fig. 1.

The coal feeders are driven by direct-current motors having a four-to-one speed range and using 70-point rheostats. The forced draft is supplied by a fan driven by a steam-turbine, the speed of which is controlled by means of a chronometer valve. The rate at which gases are taken from the boiler furnace is controlled by an uptake damper. If the design is such that most efficient combustion is obtained with the maximum damper opening, maximum speed of feeder, and maximum speed of fan, it is obvious that with a parallel control system the proper proportion between fuel feed, induced draft and forced draft will not exist at any other boiler rating.

An efficient system of combustion control should be designed to take care of characteristics such as those just referred to, and it should also correct for changes in the quality of fuel, changes in the rate of coal feed for a given speed of feeder or stoker, changes in atmospheric conditions, and other similar factors. In other words, the equipment for automatic control of combustion must be designed to bring about the correct final results in balancing the fuel supply in proportion to the demand for steam, and also to maintain the proper relation between fuel and air to give the most economical operation.

The relationship between air supply and speed of fan or position of damper is not at all consistent, and speed of the stoker, or feeder and the position of the oil or gas valve does not hold a definite relation to the fuel supply. It is thus necessary to find a definite final result as a guide in controlling the quantity-changing devices to obtain the desired relationship between fuel and air. Experience has shown that the only feasible guide for this purpose is to determine the percentage of excess air. The desired percentage of excess air for the best efficiency of combustion is that which will maintain the total losses due to excess air and unburned fuel at a minimum; or, if the deterioration of refractories is greatly increased with low excess air so that the increased cost of maintaining the furnace lining outweighs the increased efficiency with low excess air, then the percentage of excess air should be determined so as to give the most economical overall results.

The relation between the steam flow from the boiler and the air flow used for combustion is a positive, instantaneous, and correct indication of the percentage of excess air, and is being used very extensively as a guide for both hand and automatic control. This rela-

tion is basically correct because the rate of steam output from the boiler in reality represents the reading of a calorimeter showing the rate at which heat units are developed in the furnace. The flow of air as indicated by the differential pressure across the boiler, with proper precautions, is a measure of the rate of air supply to develop these heat units. Fortunately, the heat units developed per pound of air used in combustion are substantially constant for all commercial fuels, and the relation between the steam flow from the boiler and the air flow used for combustion is, in reality, a relation between the heat units supplied to the furnace in the fuel and the air supplied to the furnace for burning the fuel with the desired amount of excess air.

Automatic control equipment designed to maintain the relation correct between steam flow and air flow may be adjusted to give a different percentage of excess air at different ratings. With such a control system it is possible to take into consideration not only the desirability of operating a boiler with a minimum of total air, but also such limiting factors as deterioration of furnace lining at high ratings, low ignition temperature and smoke at low ratings with water-cooled furnaces, and other similar factors.

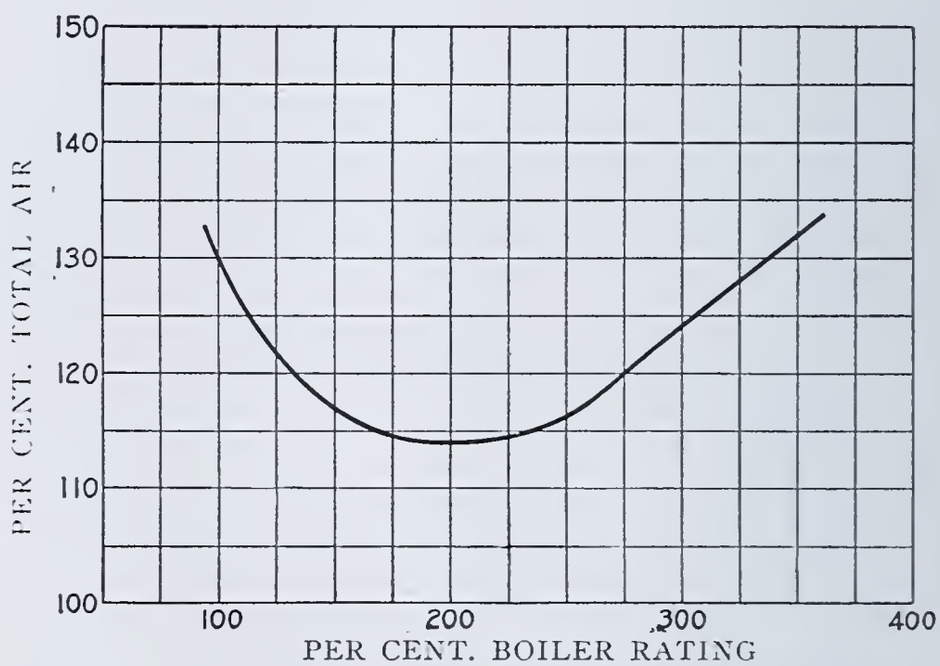

Fig. 2. Excess Air Varied with Boiler Rating.

Fig. 2, for instance, shows the total air which exists at various boiler ratings for coincidence of the steam flow and air flow pens in a boiler meter installed on a 2900-horse-power pulverized-coal-fired boiler which has bare water-wall tubes set in recesses in the refractory

furnace walls. In this particular installation, to prevent smoke, it is necessary to use about 30 per cent. excess air at 100 per cent. of boiler rating. As the boiler rating increases, the furnace temperature is increased, aiding combustion so that at 200 per cent. of rating the excess air may be reduced to approximately 14 per cent. without excessive smoke or deterioration of refractories. As the boiler rating increases from this point, the furnace temperature becomes excessive, and the refractory between the water-cooling tubes begins to run so that it is necessary to increase the excess air gradually with increasing rating above 200 per cent. until approximately 32 per cent. excess air is used at 350 per cent. of boiler rating.

In another installation consisting of 3060-horse-power boilers fired by pulverized coal and equipped with refractory air-cooled walls, efficient combustion with very little smoke may be obtained with 25 per cent. excess air at 100 per cent. of boiler rating, as indicated in Fig. 3. In this case, air cooling is not sufficient to protect the furnace

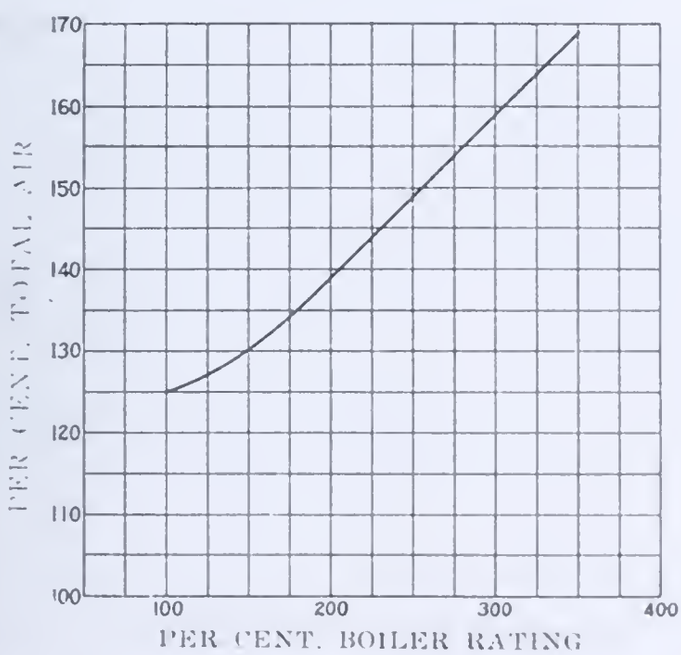

Fig. 3. Excess Air Varied with Boiler Rating.

walls at high ratings, so the excess air is gradually increased with the increased rating until it reaches approximately 69 per cent. at 350 per cent. of boiler rating. This is very easily accomplished by making a proper adjustment of the air flow mechanism in the boiler meter used in connection with the control equipment, so that the steam flow and air flow pens will coincide for the proper excess air at the various ratings.

After the initial adjustment has been made, the control equipment will automatically maintain the desired excess air at all boiler ratings. By keeping the air supply at a minimum the control equipment will not only conserve the supply of fuel and reduce the expenditure for labor, as previously mentioned, but it will effect a saving in the power consumed by auxiliaries such as the induced-draft and forced-draft fans and the stoker, the pulverizer or the motors for the pulverized-coal feeder, due to the smaller amounts of air and fuel handled for a given load on the boiler plant.

The third factor for controlling the combustion process, where forced draft is used, is found in the furnace draft which is an indication of a balance between the induced draft and the forced draft.

The system of control which must be carried out for the best results is the same whether it is operated by hand or automatically. This involves the simultaneous changing of the rate of fuel and air supply to meet the demand for steam and the readjusting of the induced draft or fuel to obtain the desired amount of excess air, and also readjusting the forced draft to maintain the proper furnace draft. If the induced and forced drafts have both been changed simultaneously with the fuel, they need only be slightly readjusted, using the excess air and furnace draft as guides in obtaining the correct final adjustment. A good fireman with hand control does this very thing, and no system of automatic control will be successful unless it carries out the same procedure as a good man would do with good controllable equipment available for accomplishing the desired results called for as he observes the combustion and operating conditions.

Safety features are an important part of modern automatic control systems, and they include travel limits which prevent overtravel of motors, rheostats, drum controllers, dampers, regulating valves and other control mechanisms. Protection is also provided against "runaway conditions" which might otherwise be caused by a short-circuit in an electrically operated control system, or by the failure of one of the connecting pipes in a hydraulically or pneumatically operated system. This feature, for instance, makes it impossible to decrease the air supply to the minimum or increase the fuel supply to the maximum without a corresponding change in the other controlled items.

Other desirable safety features include interlocks between the fuel and air supply to prevent further increase in fuel after the maximum air delivery position has been reached, or further decrease in the air supply after the minimum fuel delivery position has been obtained. This feature serves to prevent a deficiency of air at the extremes of boiler rating. The safety features indicated are very important and of considerable economic value, especially when firing fuels burned in suspension, such as oil, gas, and pulverized coal.

Provision should be made for manual control for use during starting periods or when, for other reasons, it is desired to operate the boiler by hand. One way of providing for this flexibility is to use multi-point drum switches, similar to the one shown in Fig. 4.

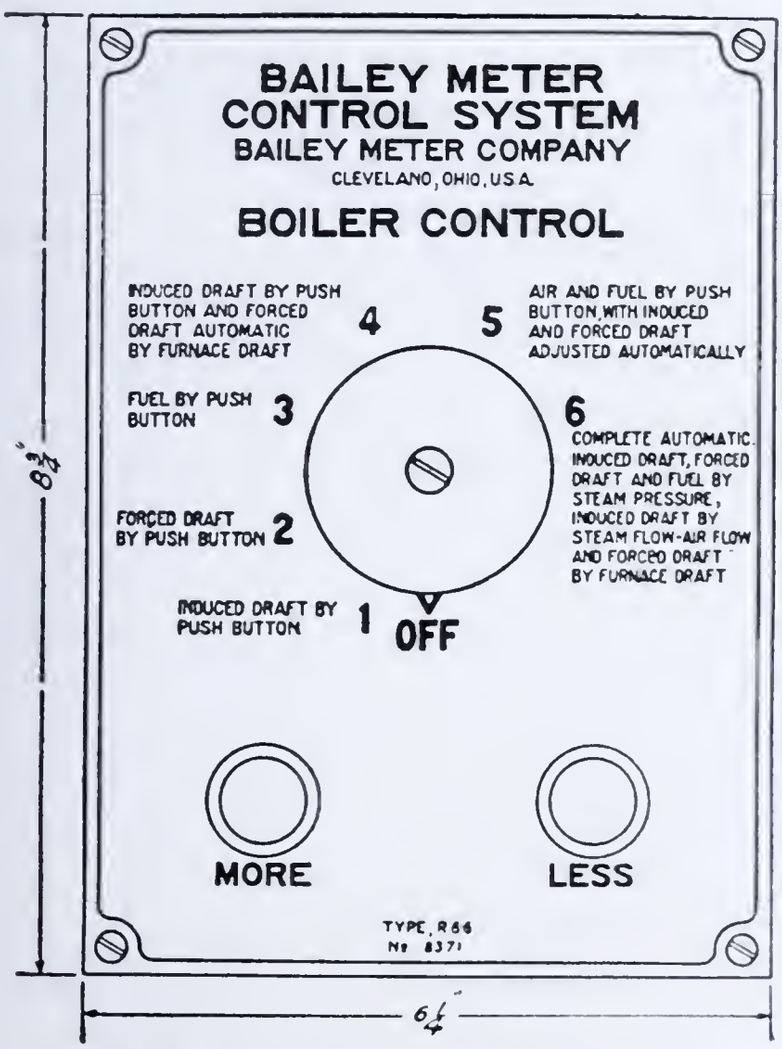

Fig. 4. Individual Boiler Drum Switch.

This type of switch permits making individual adjustments of the induced draft, forced draft, or fuel by push-button, or the boiler may be placed on partial automatic or complete automatic control, as indicated by the legend on the drum switch plate.

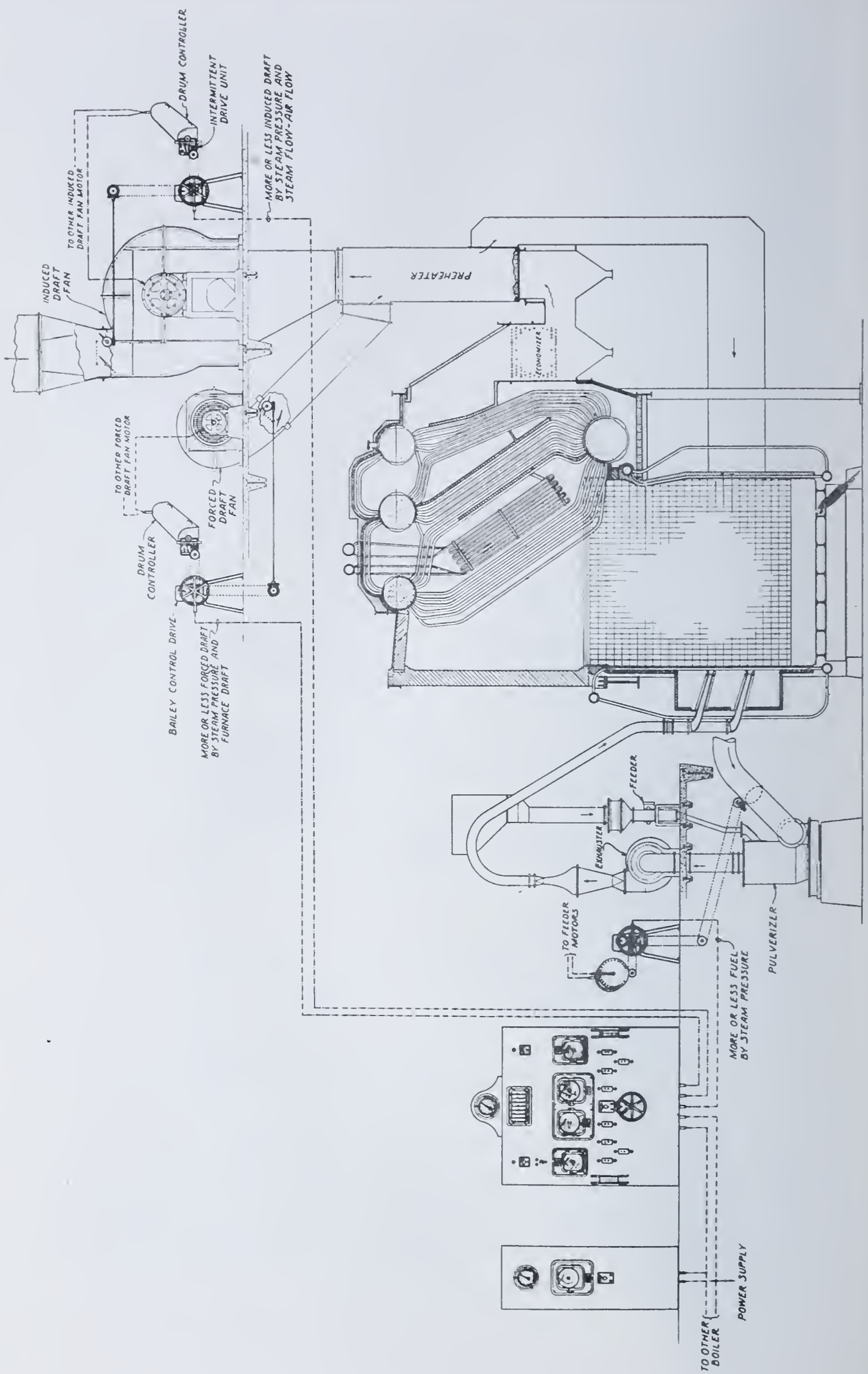

Fig. 5. Diagram for Control of Combustion with Pulverized Coal.

Fig. 5 shows a diagrammatic lay-out of automatic combustion control applied to a pulverized-coal-fired boiler of 1848 horse-power equipped with two unit mills in a central station in Kansas City. Each fan for both forced and induced draft is driven by two motors—a small motor for low ratings connected to one end of each fan shaft, and a larger motor for high ratings connected to the other end. A single 31-point drum controller is used for both motors, the first 15 points being used for the smaller motor and the remaining 16 points being used to control the speed of the larger motor. The system of combustion control shown in this diagram uses motor-operated control drives for the purpose of regulating speeds of fans, positions of dampers, and the motor rheostats of the raw coal feeder. Three control drives are shown in the diagram—one connected to the uptake damper and drum controller for the motors of the induced-draft fan, one to the forced-draft damper and drum controller for the motors of the forced-draft fan, and a third mounted back of the boiler panel and connected to the two rheostats of the feeder motor and the primary air dampers.

Each of these control drives consists of a motor-operated gear train and a solenoid-operated clutch so arranged that when an electrical circuit is closed to energize a solenoid, the clutch is caused to operate, engaging the gear train and advancing or retarding the equipment to be regulated in accordance with the demand.

The electrical impulses for energizing the solenoids come from contactors, one of which is operated from the steam header pressure as an indication of the load on the plant. This contactor is designated as the master steam pressure contactor. This contactor is wired to all the control drives so that, for any change in steam pressure, proper contacts will be made to energize the solenoids in all the control drives either to increase or decrease the fuel and air supply simultaneously as demanded by the change in steam pressure.

Two secondary or readjustment contactors are employed—the first one for the purpose of readjusting the induced draft in order to maintain the desired relation between steam flow and air flow, or combustion efficiency, and the second one for readjusting the forced draft to maintain the desired draft in the furnace.

Intermittent drive units between the drum controllers and dampers as shown in Fig. 5, make it possible to operate the dampers and

fan motors in the proper sequence. An automatic control drive is connected to each intermittent cam unit by sprockets and chain, and the intermittent cam is in turn connected to the drum controller through a spring coupling which permits a small angular travel of the uptake damper between points on the drum controller.

Fig. 6 represents the characteristic control curve for induced draft for the installation just mentioned. The lower left-hand portion of the curve is that of a louver damper, and indicates how the

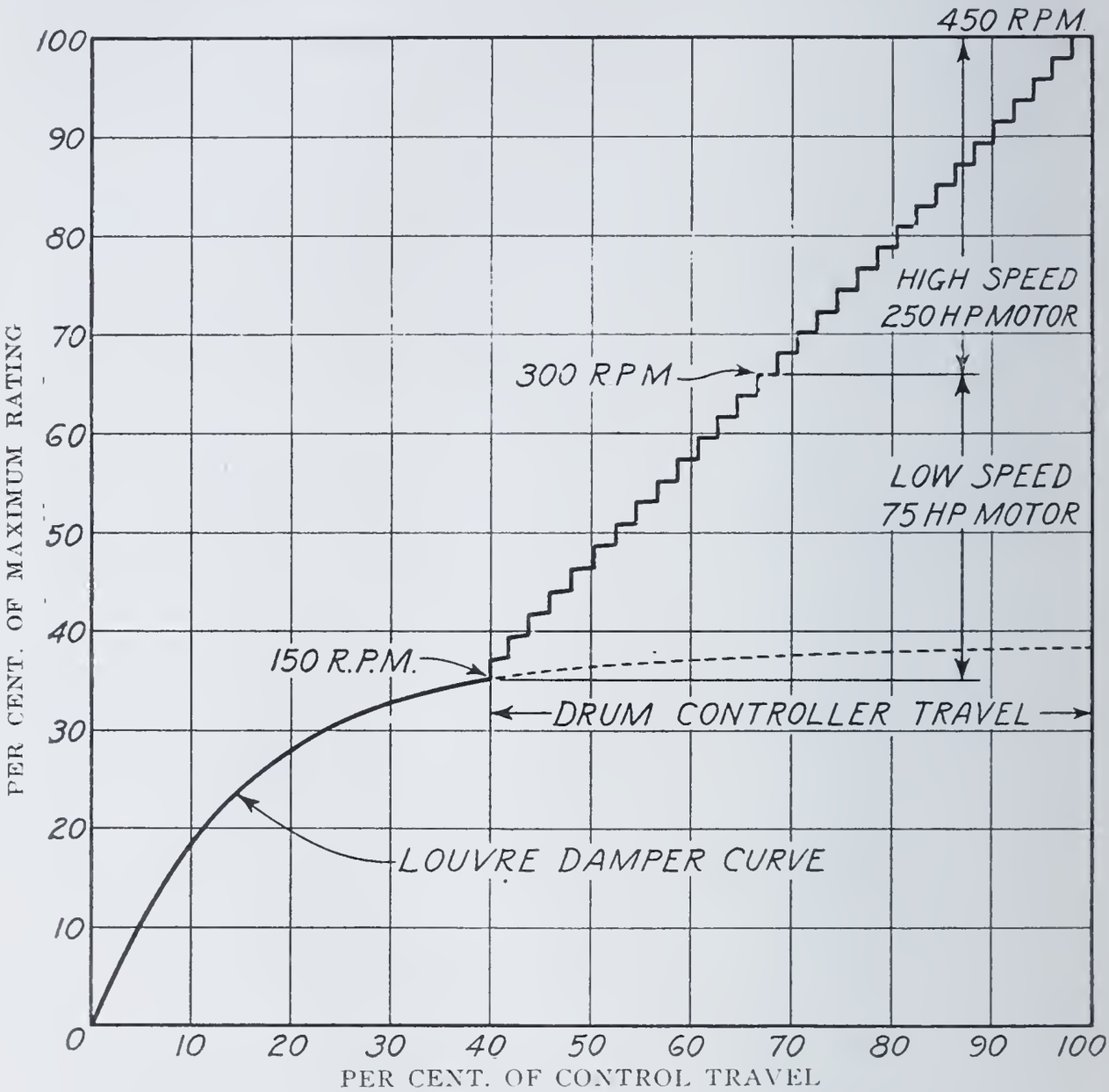

Fig. 6. Control Curve for Induced Draft.

automatic control system throttles the uptake damper to obtain boiler ratings below that corresponding to minimum fan speed. Starting at minimum boiler rating with the fan running at its lowest speed, the

damper is opened gradually over a large portion of its travel as the load increases. When the load demand becomes greater than can be handled by the fan running at minimum speed, the intermittent drive unit has reached the point where it starts to operate the drum controller, increasing the speed of the smaller motor. In other words, when the damper has been opened approximately 40 per cent. of its travel, corresponding to approximately 35 per cent. of the maximum rating, the fan motor drum controller is advanced one point. As the load continues to increase, the damper will continue to open until the intermittent drive has traveled far enough to advance the drum controller another step. This continues with increasing boiler rating until the drum controller reaches the fifteenth step. At this point the large motor is energized and both motors are designed to run at the same speed when the controller is in this position.

With a further increase in rating the drum controller is advanced another point, increasing the speed of the larger motor and, at the same time, the small motor is de-energized.

The metering equipment, the boiler drum switch, and the "start" and "stop" push-buttons for the small fan motors, the pulverizer-mill motors, and the feeder motors, are all mounted on a single boiler panel-board. A steam pressure-gage is located at the extreme top of the panel, and a multi-pointer draft-gage immediately under it indicates such factors as furnace draft, uptake draft, draft at economizer and air heater outlets, forced draft at pulverized-coal burners, and exhauster suctions. The boiler meter records steam flow and air flow, while another recorder in the same casing records feed-water flow, steam pressure and steam temperature. Two four-pen temperature recorders record flue-gas, feed-water, preheated air and mill outlet temperatures.

The diagrammatic lay-out in Fig. 7 shows the control equipment installed at the Gilbert station of the New Jersey Power and Light Company. This station consists of a 12,000-kilowatt, high-pressure turbine and a 43,000-kilowatt, low-pressure turbine supplied with steam by two Babcock & Wilcox cross-drum boilers designed to operate at 1300 pounds pressure. Each boiler is equipped with a gas as well as a steam reheater, an economizer, and an air preheater. Fans driven by two-speed, squirrel-cage motors and special inlet control vanes are used for both the forced and induced draft.

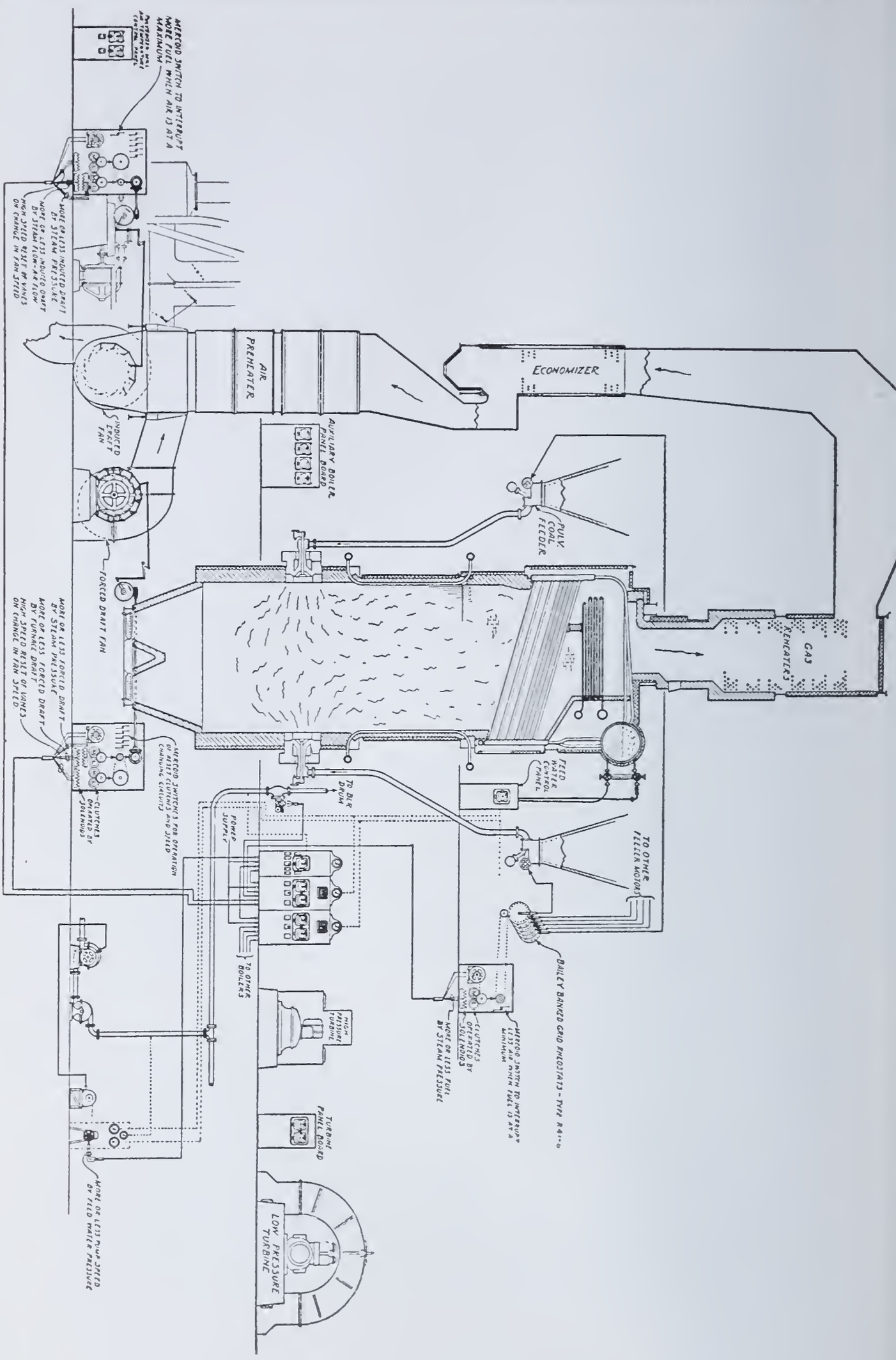

Fig. 7. Diagram of Control Equipment at Gilbert Station.

There is no division between the boiler and the turbine room, and a single operator stationed at a centrally located panel-board between the boilers and the high-pressure turbine is responsible for the operation of the entire plant. The important indicators and recorders which give essential information for guidance in operating the boilers, are mounted on the centrally located panel previously mentioned, whereas the recorders of secondary importance, such as the flue-gas, preheated air and the feed-water temperature recorders, the temperature recorders for the air entering and leaving the pulverizer mills, and the instruments recording the temperature and pressure of the steam at the turbine throttle, are located on auxiliary panels.

The feed-water for the two high-pressure boilers is supplied by two pumps in series—one a low-pressure, variable-speed pump driven by a slip-ring motor and the other a high-pressure, constant-speed pump. The variable-speed pump is controlled automatically to maintain a constant header pressure by means of a pressure contactor and a control drive connected to the drum controller for the slip-ring motor.

Boiler water-level recorders and indicators are used to show the water-level in the boilers at all times. These are calibrated to read direct in inches of water in the boiler drum. Selsyn motors are used to operate water-level indicators at the top of each of the individual boiler panels, as well as in the pump-room, as indicated. These level recorders are also equipped with Mercoid switches which close when the water-level reaches a predetermined high or low point, thereby operating signal lights and sounding alarms.

The boilers are equipped with complete combustion control. They are fired with pulverized coal using the bin system with six feeders to each boiler. The furnaces are fired from two sides, with three horizontal turbulent-type burners on each side of each furnace and a small control drive connected to a bank of six feeder motor rheostats controls the fuel supply. Control drives are also used to regulate the fan motor speed as well as the inlet control vanes on the fans for both forced and induced draft.

On installations such as this where two-speed fan motors are used and the desired quantity of air is obtained by throttling dampers or inlet vanes, a special control drive is necessary. The curves in

Fig. 8 represent the functioning of the control under such conditions. With the small motor in service in the case of the two-motor arrangement, or with a two-speed motor running at low speed, the damper or inlet vanes on the fans are opened with increasing boiler rating as indicated by line A-E. If the load on the boiler continues to increase so that more air is required, a Mercoid switch in the control drive is automatically closed at the point E to put the larger motor into service or to change the motor connections so that the fan will operate at full speed, tending to increase the rating along the dotted line E-F, at a speed in accordance with the acceleration of the

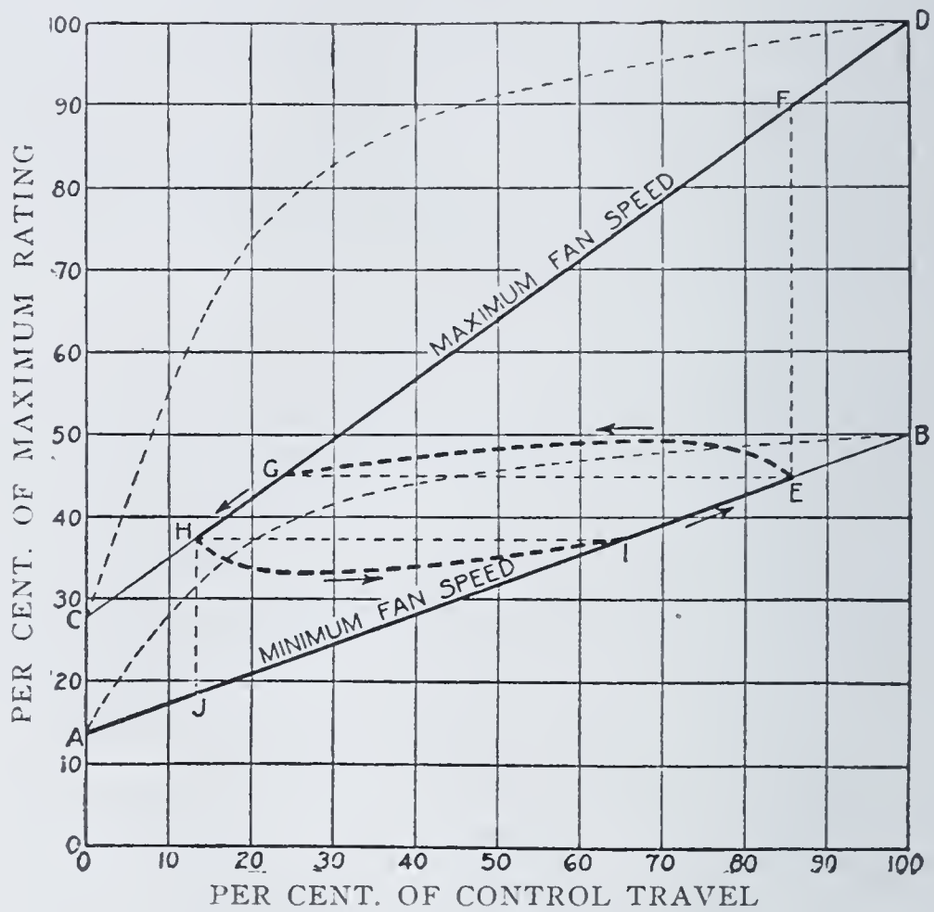

Fig. 8. Control of Damper on Inlet Vanes with Two-Speed Fan Motors.

fan motor. Simultaneously, however, with an increase in fan speed, the damper or inlet vanes on the fans are throttled back as indicated by the curve E-G at a high rate of speed with practically no change in the amount of air delivered, although after the change the motor will be operated at the higher speed.

For a continued increase in load on the boiler the air supply is increased by again opening the damper or inlet vanes as indicated by the line G-D until the wide open position is reached with the fan at maximum speed.

On a decrease in air rating the same paths as shown in Fig. 8 are followed in a reverse direction, except that an overlap is provided at the point of change in speed of the fan, so that "hunting" will not occur at the change-over points. When the point H is reached, the fan speed is reduced and the tendency is to follow the path H to J, whereas the actual path followed will be H to I, as shown, since the inlet vanes will be opened at a high rate of speed at the same time the motor is decelerating.

Various types of automatic equipment for feed-water control have been on the market for a number of years, but the progress in power-plant design, especially in central stations, has been such during the past few years that former types of feed-water regulators are not entirely satisfactory for all present-day boilers, some of which must operate at high pressures over extremely wide ranges in boiler rating and with slight capacity for water storage.

Within the past ten years the amount of water storage in a boiler has been reduced from approximately one pound to 0.2 of a pound of water per pound of steam generated per hour at maximum rating. Furthermore, the modern unit with water-cooled furnace walls has only about one-half as much of its water storage in the drum as was the case with the average boiler of ten to fifteen years ago. Due to this change in relative water-storage capacity of boiler drums it would require only about 1½ minutes to two minutes to evaporate all the water out of a modern boiler drum if something should happen to the feed-water supply when operating at maximum rating. Such a unit permits the feed-water control only about one-tenth the time in which to function upon a change in conditions as compared with the older boilers.

With the increased rate of steaming of modern boilers, a very much greater portion of the volume below the surface of the water is occupied by steam. This was found to be approximately 24 per cent. in the case of a 2600-horse-power, cross-drum boiler equipped

with water-cooled furnace walls, as indicated by the curves in Fig. 9. Since only 15 to 20 per cent. of the total volume of water in a modern boiler is within the drum at normal water-level it is evident that the drum water-level will be seriously affected by changes in the rate of steaming. Feed-water control for boilers of this type can not operate very successfully in the ordinary manner from an indication of level alone, due to the fact that the water-level is not a correct indication of the actual quantity of water in the boiler. A feed-water

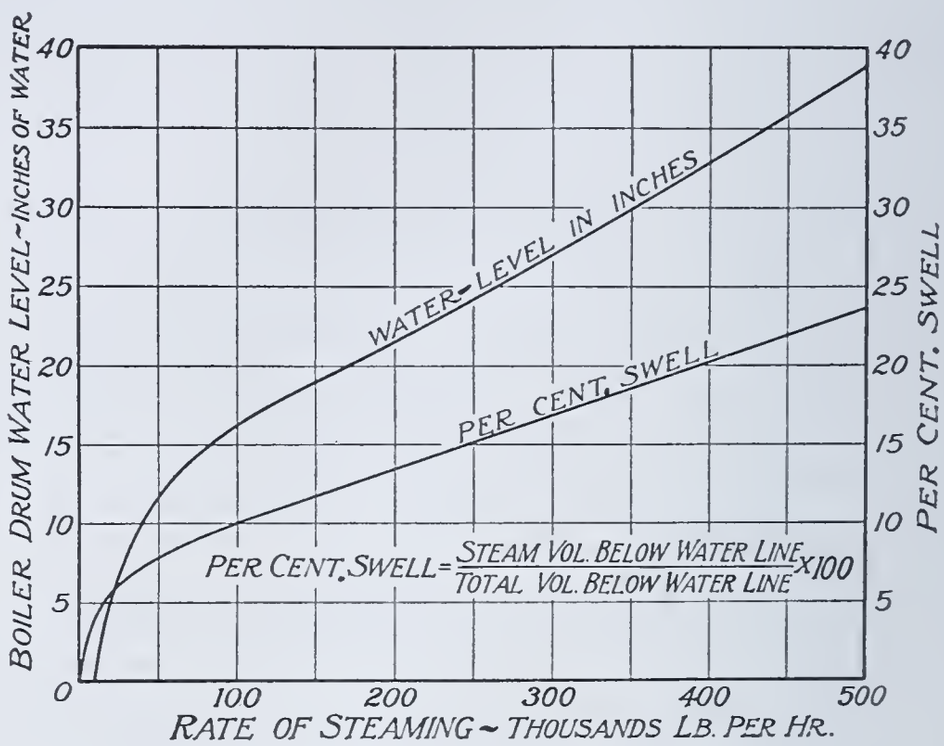

Fig. 9. Boiler Water-Level at Different Rates of Steaming.

control for boilers of this type must be extremely rapid in operation to keep the level within normal limits during large changes in load. In some cases the only possible way to maintain the water-level within safe operating limits is by means of a control which will maintain a high water-level at high boiler ratings, thus providing increased storage so the level will not drop below the water wall tube connections or below the drum when "shrinkage" takes place following a reduction in steaming rate.

Extreme variations in level may be caused by sudden fluctuations in load. An increase in load, for instance, resulting in a slight drop in steam pressure, is immediately followed by increased steam generation due to the heat stored in the boiler water. This will cause the water-level in the boiler drum to rise momentarily due to the in-

creased volume of steam bubbles below the water-level. A feed-water regulator operating from water-level alone will tend to close during such an increase in boiler rating. Similarly, a sudden decrease in load will result in a drop in water-level of the boiler drum due to the decreased volume of steam bubbles below the surface of the water. This will cause a so-called "single-element" feed-water regulator functioning from water-level, to increase the flow of water to the boiler. Such a regulator is likely to "hunt" with fluctuations in the rate of steaming and is therefore unsuited for controlling feed-water flow to a large boiler unit generating high-pressure, high-temperature steam, and operating at several hundred per cent. of rating.

The difficulties outlined have been remedied by an automatic feed-water control system which functions in accordance with the rate of steam flow from the boiler, the rate of water flow to the boiler, and the water-level or quantity of water in the boiler drum. With this control system incorporating the three elements—steam flow, water flow, and water-level—there is a definite rate of feed-water flow required to correspond with each rate of boiler steaming and boiler water-level.

This three-element, feed-water control is designed to maintain a feed-water flow at all times substantially equal to the rate of steam flow. In other words, it tends to maintain a constant weight of water in the boiler at all rates of steaming. Under such conditions the water-level as shown by the gage-glass will be low at low rates of steaming and high at high rates of steaming. This has the advantage of providing a safety margin of water storage at high rates of steaming to guard against a sudden loss of load which would tend to drop the water out of the boiler drum and possibly result in the burning of the boiler or furnace wall tubes. This system will also permit a very sudden increase in load on the boiler with a corresponding increase in apparent water-level due to swell, without the danger of water being carried over into the turbine.

A diagrammatic lay-out of an installation of three-element feed-water control is shown in Fig. 10. This system is based on metered results, the three elements of steam flow, feed-water flow and boiler water-level being co-ordinated by means of linkage so as to operate the Selsyn transmitter through a torque amplifier. A receiving Selsyn motor mounted on the flow-regulating valve in the feed-water line

accurately follows every movement of the sending Selsyn transmitter and in doing so moves a pilot-valve in the flow-regulating valve from its neutral position. This applies oil pressure to the proper side of the operating piston which opens or closes the valve to produce the required rate of flow. As the piston moves, the frame or stator of the receiving Selsyn is rotated in such a way that the pilot-valve is returned to its neutral position and the flow-regulating valve is held in the new position.

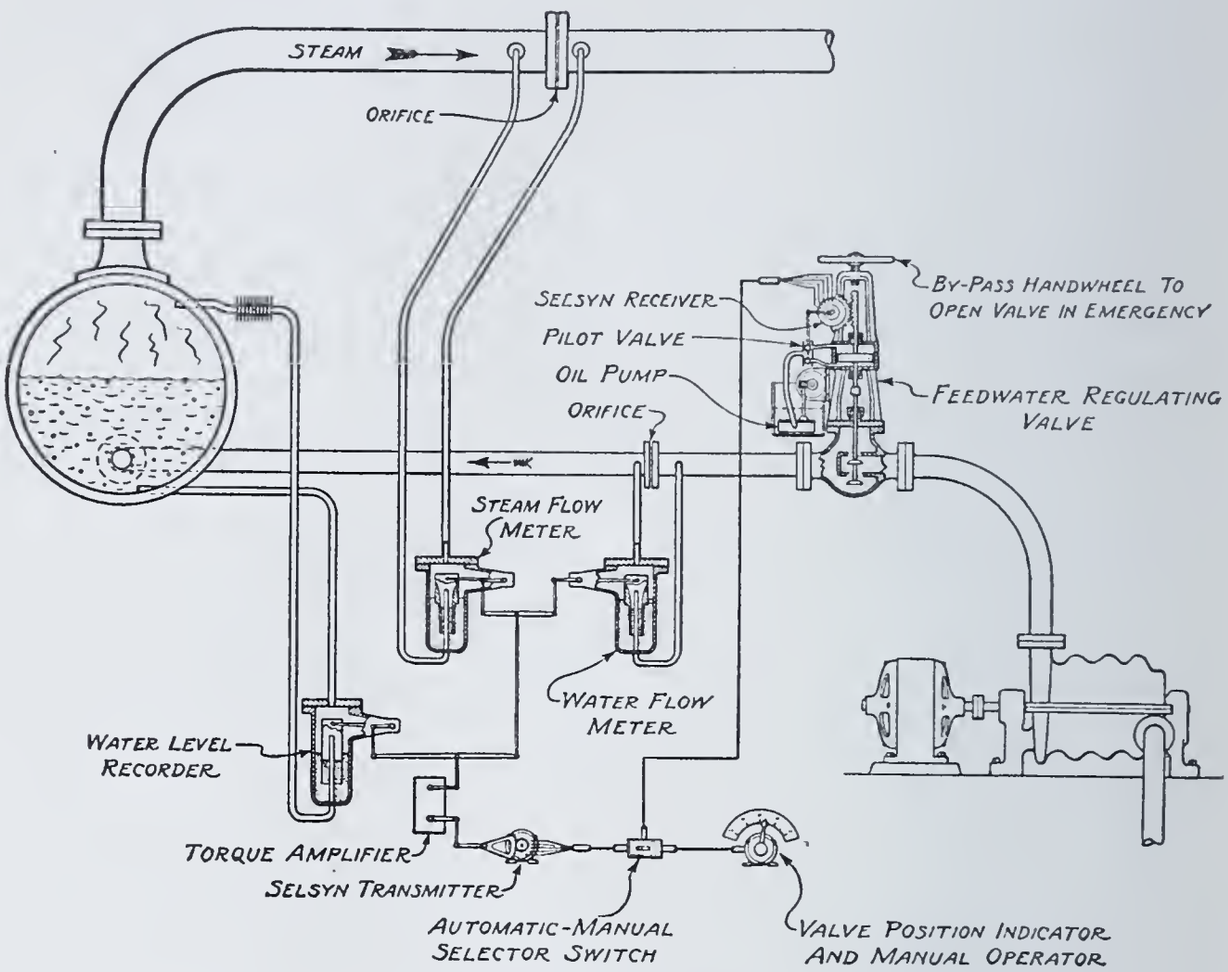

Fig. 10. Diagram of Three-Element Feed-Water Control.

The Selsyn hydraulic feed-water control valve is provided with a motor-driven, oil-pumping unit mounted on the valve, resulting in a self-contained unit. This eliminates the necessity of expensive oil piping and results in maximum flexibility. The design of the system is such that full power is available for operating the valve regardless of the magnitude of the change to be made in the valve opening.

A selector switch on the boiler panel provides for automatic or manual operation of the feed-water control system. When in the "automatic" position the Selsyn-operated position indicator, also

mounted on the boiler panel, shows the valve position at all times. When the selector switch is thrown to the "manual" position the Selsyn indicator becomes a sending unit and the control valve may be regulated by hand, by means of a small knob on the end of the Selsyn shaft.

For low-pressure and medium-pressure boilers carrying fluctuating loads, the linkage may be adjusted so that the water-level in the drum is permitted to vary with boiler rating as previously mentioned. A low water-level at low boiler rating provides room for expansion with increasing rating, thereby tending to eliminate the possible carrying over of moisture. A correspondingly high boiler water-level at high ratings also provides protection against a sudden loss of load with the consequent shrinkage of volume.

Fig. 11 shows a flow-meter chart containing records of the feed-water flow and boiler water-level, on which the corresponding steam flow record has also been drawn to illustrate more clearly the results obtained with this feed-water control system. The maximum capacity of the water flow meter is 400,000 pounds an hour, whereas the steam flow meter has a maximum capacity of only 350,000 pounds an hour, which accounts for the fact that the water flow record is approximately three small chart divisions below the steam flow. A close inspection of the chart will show that these two records are substantially equal at all times on a quantity basis. The range of the water-level recorder is zero to 40 inches, measured from the lower water-level recorder connection which is 12 inches above the bottom of the 60-inch drum. In other words, a recorded level of 16 inches corresponds to 28 inches of water in the drum, the level being two inches below the middle of the drum.

This chart illustrates the operation of three-element feed-water control installed on a boiler fired by pulverized coal and operating at 400 pounds pressure. When these records were obtained, the control had been adjusted to permit a variation of 12 inches in boiler water-level in going from zero to maximum boiler rating. The chart shows a fairly definite level for each rate of steaming and indicates a change in level of approximately one inch for a change in boiler rating of 25,000 pounds an hour.

Standard metering equipment is used in connection with the three-element feed-water control system. One recorder combines a

feed-water flow meter and a boiler water-level recorder, while the adjacent recorder for boiler steam flow comprises the standard boiler meter for steam flow and air flow. A selector switch and a valve

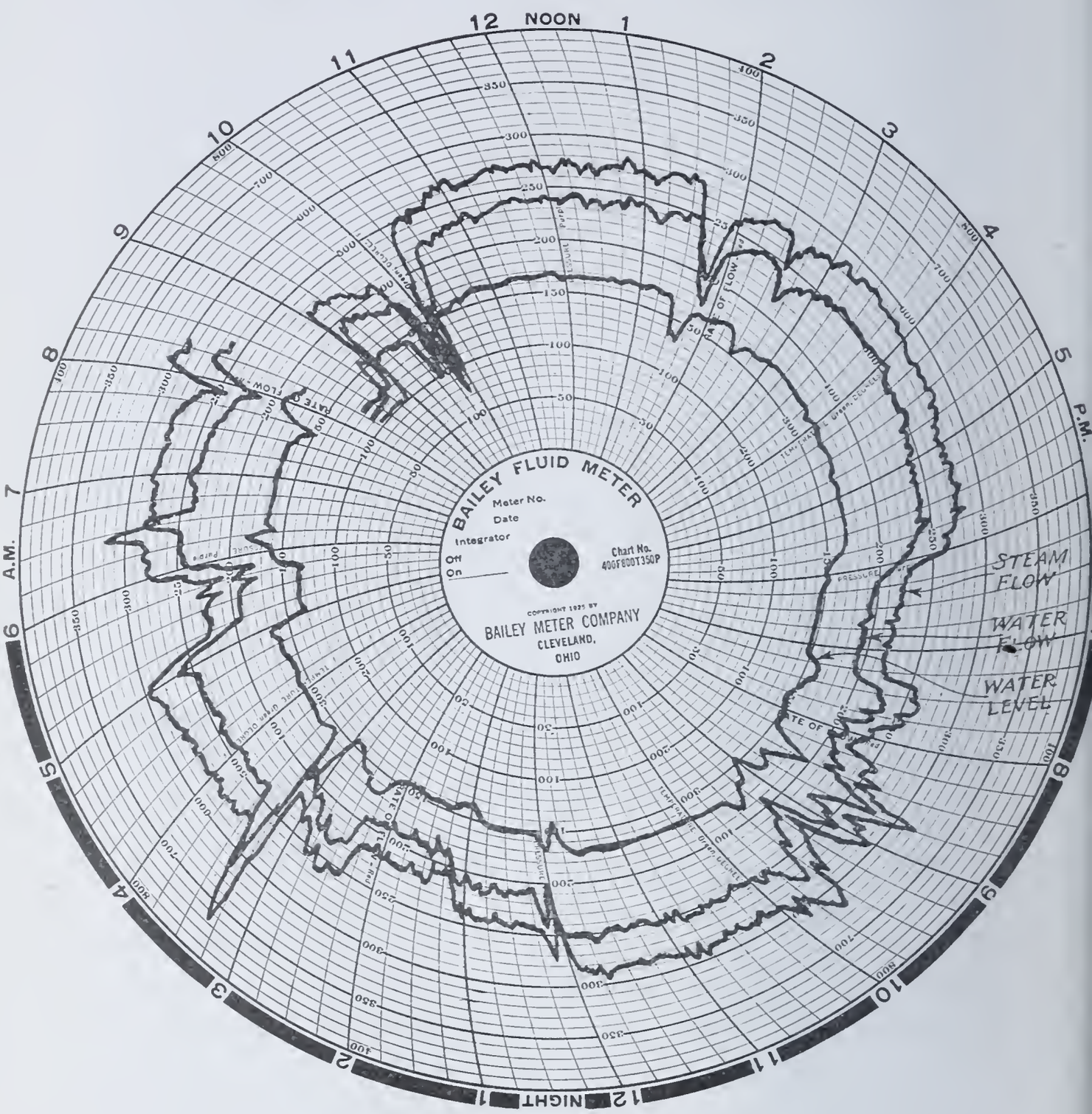

Fig. 11. Chart for Three-Element Feed-Water Control, Showing Variable Water-Level.

position indicator, providing for manual control from the boiler panel when desired, are mounted directly below the meters.

The four boilers fired by pulverized coal, each having a maximum capacity of 560,000 pounds of steam an hour, recently installed in the Charles R. Huntley station 2 of the Buffalo General Electric Company, are equipped with complete automatic combustion control and three-element feed-water control.

The Selsyn hydraulic three-element feed-water control valves for two of the boilers at this station are installed at approximately the same level as the boiler drums as shown in Fig. 12. Since the Selsyn method of electrical transmission is used between the meters (which are the primary source of control) and the regulating valves, these valves may be installed any place in the boiler feed line, either above or below the boiler water-level, and they need not be adjacent to the boiler drum.

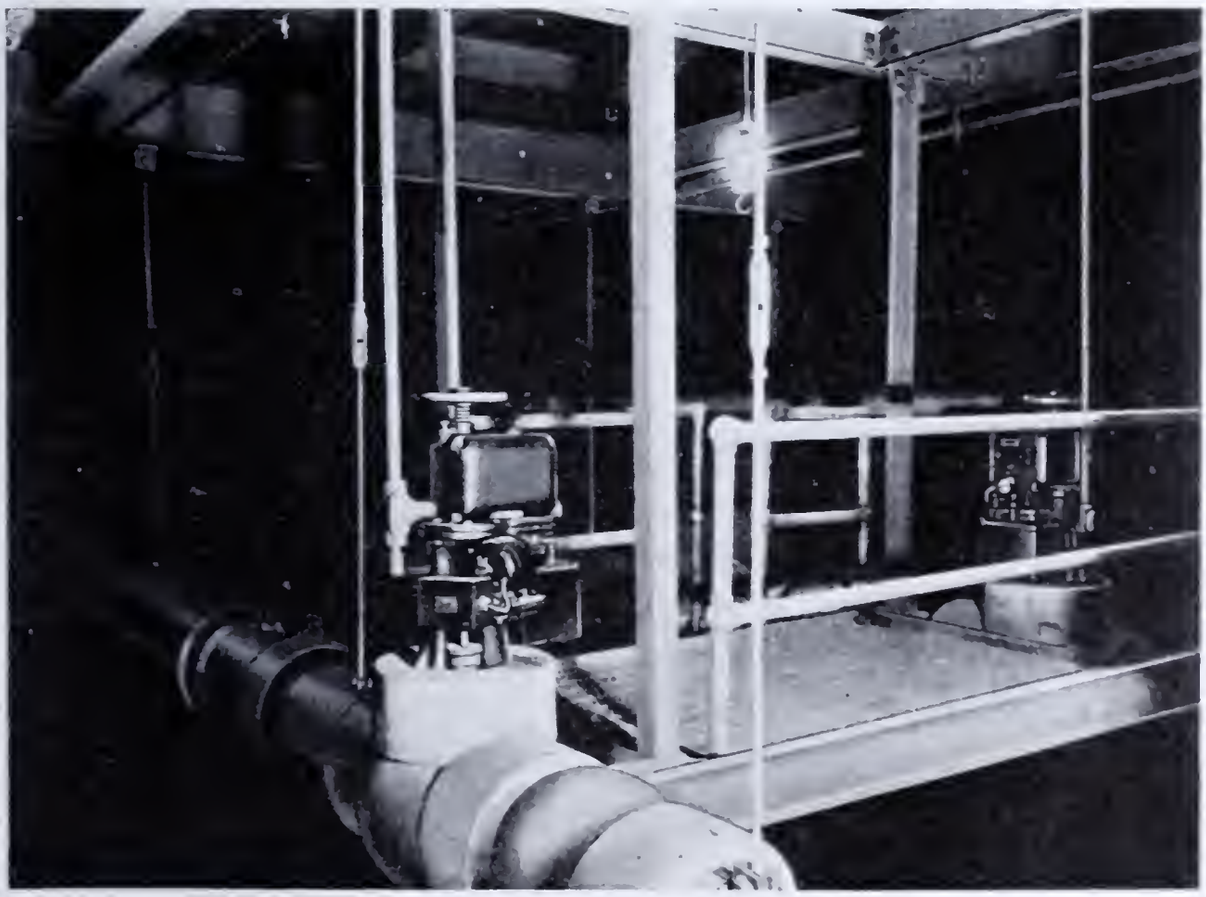

Fig. 12. Selsyn Valves.

An interesting installation of automatic control exists on the three new boilers of 1400 pounds pressure, each having 10,699 square feet of heating surface, in station A of the Pacific Gas & Electric Company on the west coast. These boilers, two of which are of the

reheat type, the third being of standard construction, supply steam to two 50,000-kilowatt vertical compound turbines. All three boilers are equipped with economizers and air preheaters and are fired with combination gas and oil burners.

The fuel supply and air supply to all boilers are controlled in parallel in response to impulses originating at the master pressure contactor in accordance with variations in steam pressure.

Any deviation of the steam flow and air flow pens of the boiler meters from coincidence causes a readjustment to be made in the induced draft of the individual boiler so as to maintain the most economical combustion efficiency at all times. Any deviation of the furnace draft from the desired value causes readjustment in the forced draft so as to re-establish the furnace draft desired.

As previously mentioned, the high-pressure boilers at station A are equipped with combination gas and oil burners. Separate control drives are provided for each.

The gas-valve is of standard chronometer design, but because of the wide range of the burner used, a special double-ported oil-control valve is required. At low boiler ratings a large part of the oil is recirculated through the three-way valve and recirculating pump. The oil supply to the boiler is increased by closing the special control valve, gradually shutting off the oil return, while the pressure of the oil supply is maintained constant.

After the recirculated oil has been completely shut off, if a further increase in boiler rating is required, the oil pressure is doubled by passing the oil supply through the three-way valve and then through the recirculating pump, which now becomes a booster pump. The control drive also continues to operate the regulating valve, which now begins to open, using a smaller set of ports, thereby permitting oil under a higher pressure to be supplied to the burners. During this period of operation at comparatively high boiler rating, no oil is recirculated, as the three-way valve is open only to the oil supply line. The three-way valve is hydraulically operated from a solenoid pilot-valve which is operated automatically from the fuel-control drive at the proper time. With a decrease in rating, the sequence of operation is reversed.

Each boiler is also provided with an oil-gas transfer switch so as to permit transferring the control circuits from the gas-control

drive to the oil-control drive, in case oil is burned, and vice versa when gas is burned.

Each boiler is provided with one forced-draft and one induced-draft fan, each driven by a low-speed motor on one end of the fan shaft, and a motor of higher speed on the other end. Draft control is therefore accomplished by the operation of fan inlet vanes and by changing fan speeds as is done at Gilbert station (previously described) and as represented by the curves in Fig. 8.

In one installation, two Selsyn hydraulic three-element feed-water control valves are installed in the feed line to one of the high-pressure boilers. These valves are installed in series and are normally operated in parallel, although either one may be operated singly under automatic control, with the other in its wide open position.

Boilers operating at pressures from 1200 to 1400 pounds are not ordinarily troubled by level variations due to fluctuations in the rate of steaming. This is accounted for by the fact that the specific volume of the steam approaches that of the water so that the "swell" becomes negligible.

For operation under these conditions the three-element feed-water control linkage may be adjusted to maintain a substantially constant water-level in the drum at all times.

In a properly designed automatic control system, adjustments may be made when the equipment is placed in service, to duplicate ideal or test conditions in every-day operation. The most important feature about such automatic apparatus is that it is continually "on the job" and constantly checking and readjusting itself whenever necessary, to meet all of the many fluctuations and variations encountered in operating a steam-boiler. It is virtually impossible for a boiler operator to furnish the supervision necessary for continuously making the slight adjustments and readjustments which can be contributed by an automatic combustion control.

The proof of the satisfactory operation of, and the results obtained by, complete automatic boiler control are found in the efficiency obtained by boilers provided with this equipment, and in the rapidly growing number of installations.

DISCUSSION

T. E. Purcell, *Chairman:** We will now proceed with the discussion. We have sent invitations to several to discuss these papers. The first one on the list is Mr. A. J. Boynton, of Chicago.

A. J. Boynton:† As is well known to many of you the company with which I am associated has an interest in the manufacture and sale of the Askania system of automatic control. My discussion of the papers which have been read may seem, therefore, to be lacking in impartiality and in some degree actuated by commercial rather than technical motives. I hope, however, that the few words which I have to say will be recognized as spoken in the spirit of fairness, and I would call attention to the fact that engineering in these days is so highly specialized that the most truly interesting and profitable sources of information are in the hands of people who are developers, designers and builders of equipment for sale. With this apology for what may seem to be a violation of the traditional rules of a technical society, I offer the following remarks.

In listening to the papers which have been read this afternoon, I am impressed by the amount of attention which the writers have given to the matter of lay-out and connections for effecting control in the installations which they have described, in comparison with the practically total omission of all reference to the regulating unit. This is of interest to all purchasers and users of automatic regulating equipment on account of the fact that the complexity or simplicity of lay-out and connections varies greatly with the nature and design of the regulating unit. By regulating unit I mean the combination of equipment for transmitting impulse with means for introducing into the system an auxiliary power capable of effecting regulation even when the latter requires forces of very considerable magnitude. The simplest form of regulator may be typified by the diaphragm valve in which the impulse operates directly upon the valve.

Wherever large forces are necessary to move valves or other means of control, the regulation must be indirect. By this term is meant a system wherein the medium to be regulated does not directly move the regulating valve but governs a source of auxiliary power by means of a transforming device. The auxiliary force may be sup-

*General Superintendent of Power-Stations, Duquesne Light Co., Pittsburgh.
†Vice-President, H. A. Brassert & Co., Chicago.

plied by oil, water, air, gas under pressure, or electric current. It operates the regulating means which may be a cylinder or an electric switch of some form.

The most important part of the regulating system is the transformer which should fulfil the following requirements:

1. It must be simple and easily comprehensible in its design.
2. It must be dependable and safe in operation.
3. It must operate with extremely small impulse forces, a stipulation which requires supports which are nearly frictionless. It must be so arranged that the impulse system transmits no weight of moving parts, but only the impulse in accordance with which regulation is to be effected.
4. It must respond to any momentary variation in the impulse, but must come back into median position immediately after effecting the regulation. This condition necessitates the elimination of all accelerating forces, and requires that the moving parts be extraordinarily light.
5. The transforming member must not transmit to the impulse system or the adjusting system any reaction from the auxiliary power employed.
6. The transforming member must apply the auxiliary power to the regulating piston or other actuating device in such a way that the velocity of action of the controlling member increases proportionately to the variation from the value for which the regulator is set.

Such a regulating unit may serve its purpose perfectly under conditions where no lag exists in the system outside the regulator; that is, such a regulator will be completely satisfactory if applied to such a problem as the regulation of the pressure or flow of a gas at a point in close proximity to the regulator. Where a lag exists due to distance or to inertia in the regulated system, the regulating unit must include means of overcoming the lag due to distance or inertia and of avoiding "hunting."

Many purposes to which regulating means are applied involve a maintenance of a predetermined ratio between two forces. These may be forces of pressure or of differential pressure corresponding to flow. In the latter case there are four forces which require to be balanced against each other. A regulating unit to be of the utmost value

under these circumstances should have means of balancing these four impulses within itself and of effecting the application of the auxiliary regulating force in accordance with their resultant. The regulating unit should furthermore include means of varying the ratio between each pair of forces. This ability permits the regulating unit to maintain a definite relation between two pressures or two flows and also confers the ability to vary this ratio at will. It is desirable that variation in the ratio should be easily and promptly accomplished either manually or by automatic means.

In the above list of requirements immediate response of the regulator to an impulse was specified but the importance of such immediate regulation was perhaps not sufficiently emphasized. There are many situations in which any regulator which does not act instantaneously to effect a correction can not effect such a correction at all. There are certain systems of regulation in which a lapse of several minutes exists between the impulse and the resulting regulation. In consequence, it is entirely possible that the regulating action may be directed to a condition which no longer exists.

It is also highly desirable that a system of regulation be prepared to receive and to operate with impulses of varying intensities and conveyed by different media. For example, in the Askania system we have first of all the transmission of an impulse by means of a leather diaphragm. For high pressures a metallic diaphragm may be used. For still higher pressures an impulse system consisting of a Bourdon spring is employed. For steam work a Sylphon diaphragm or a combination of Sylphon diaphragms may be used. Finally, there has been developed the mercury balance system which is capable of operating at a different pressure corresponding to a few inches head of water with a static pressure up to 2000 pounds per square inch on both sides of the balance.

Where the regulating unit fulfils the requirements specified, the lay-out of any regulating system becomes extremely simple. For example, the problem of regulating input of feed-water to a boiler in proportion to the outgo of steam may be carried on by means of the differential pressures through two orifices, these pressures being transmitted to the impulse systems of a single regulator. The final correction of flow of water by means of the height of the water in the boiler may be effected by an automatic governing of the ratio between

the two primary impulses. The latter requires a secondary regulator operating on the differential pressure between a column of water of fixed height and the column of water in the boiler.

Other problems of regulation may be solved by very simple methods. Lack of time prevents a further discussion of these in detail. The point which I wish to emphasize is that the basis of successful regulation is the regulating unit. Failure to conform to requirements which I have stated leads to the inclusion in regulating systems of much that might be omitted with equally good, or better, results and fosters a complexity which is puzzling to the operator and which is often considered a reason for manual instead of automatic regulation.

In making the above remarks I do not wish to appear to be making a comparison between any specific systems of regulation. All of these systems have been carefully worked out and are based on wide experience. I believe, however, that a very considerable emphasis of the importance of the regulating unit should be made in the discussion of any system of regulation and its application.

T. E. Purcell, *Chairman:* Mr. Boynton has touched on a subject that many of us have discussed time and again; that is, whether or not we are going to devote these meetings to sales talks. We are not doing that. We are not devotees of pure science; we are engineers who make a living by applying engineering to industrial problems. We come here to find out the latest development in the things we use and to some extent to tell the manufacturers our troubles. So we must have the designers and the manufacturers of equipment tell us what they have done and can do; and of course they have to talk about the things they make and know about.

We are going to hear now from some of the users of control equipment. The Youngstown Sheet and Tube Company has a very large installation of control equipment and its experience will be of value to all of us. Mr. A. L. Wilhoite of that company will now talk to us.

A. L. Wilhoite:* If my inferences from Mr. Hammond's paper are correct, I am pleased to note that he admits that, at least in the past, automatic control equipment has always lacked something

*Steam Engineer, Youngstown Sheet and Tube Co., Youngstown, Ohio.

to make it duplicate the results which can be attained by hand operation. These limitations of automatic control equipment are not confined to boiler houses. The anticipatory feature has always proved a serious stumbling-block. He apparently admits, as at least some have contended, that hand control can produce unbeatable results, although infrequently attained. I have in several cases, seen the regular operator on certain equipment produce better records with hand control than the automatic control would show.

Anticipatory features are a necessity to attain the desired goal. Boiler automatic control from steam flow is, no doubt, a vast improvement over previous developments. Gas fuel, atomized liquid fuel, and pulverized solid fuel, tend towards some simplification of the automatic control problem in the boiler house.

Stoker-fired boilers present more serious troubles. The inertia of the large fuel mass always contained in the furnace, makes its response to automatic controls sluggish particularly during rapidly fluctuating loads and sometimes at the expense of economy. Automatic controls frequently produce remarkable results particularly for certain load conditions, or for some ranges of loads but sometimes at the expense of flexibility under all conditions. This is apparently admitted because all automatic controls are provided with switches or levers for shifting from automatic to hand control. There is, possibly, a tendency at times to extend control too far; we have controls on controls. It is good business for the manufacturer if these new developments can be realized on, and good business for the purchaser if he can realize a profit on his investment.

There is usually a reduction in common labor with the installation of automatic controls, and possibly an increase in skilled labor. If the figures are available, it would be of interest for Mr. Hammond to state the relative labor costs in two similar boiler houses, at least as to capacity—one equipped with automatic controls, such as outlined in his paper, and one without such equipment.

Also, unless I have overlooked some features, Mr. Hammond has left for future development, the problem of automatically duplicating hand control when two or more kinds of fuel are being supplied to a boiler at the same time, through different burners and in varying ratios.

Mr. Hammond states that the flow of air as indicated by differential pressure across the boiler, with proper precautions, is a measure of the rate of air supply. Too much emphasis can not be placed on the words "with proper precautions."

While the theoretical amount of air required per heat unit of commercial fuels is substantially constant, the mechanics of firing different fuels involves varying quantities of excess air which aggravate the automatic control problem, particularly when two fuels are used simultaneously.

Mr. Hammond's three-element feed-water control functioning from steam flow, feed-water flow, and feed-water level is very interesting and if it faithfully performs according to the plan outlined, it will no doubt satisfy a long-cherished ambition.

Mr. Hammond has outlined functions claimed for his equipment, which functions are not now performed by automatic equipment as installed in many of the present-day, so-called, modern boiler houses—boiler houses which, in some cases, show remarkable efficiencies. Can he show further improvement in these modern boiler houses by the application of his controls, and will the gain be commensurate with the extra cost?

There are four exacting requirements of any good boiler house—safety, uniform steam pressure, high efficiency, and low operating costs. It is easily possible to obtain any one of these desirable characteristics but a combination of the four is a difficult problem; Mr. Hammond, I believe, has failed to dwell on the safety features of his equipment except from the standpoint of feed-water.

V. P. Griffin:* The paper by Mr. Hammond has set forth in a comprehensive manner the essential features of a complete system of automatic combustion control.

Several manufacturers now produce equipment which will control the most complicated system better than it will be controlled by the average operator.

Whether or not combustion control can be economically justified in a given plant, whether full or partial control shall be applied, what number of units shall be equipped, and what type of control equipment is best suited to the local conditions are problems requiring careful study.

*Results Engineer, Duquesne Light Co., Pittsburgh.

The author has discussed increased thermal economy, labor saving, increased capacity, reduction in boiler outages, and greater return on capital invested in large boiler units as being the principal benefits to be gained from the automatic control of boilers.

With respect to economy, there have been instances where savings of several per cent. have been credited to the installation of equipment for automatic combustion control. Where enormous savings result, an analysis of conditions before and after the installation will show that a large percentage of the gain was incidental to the control equipment. It will be found that, simultaneous with the installation of control equipment, stoker drives and damper mechanisms have been altered to improve their operating characteristics so as to meet fluctuations in load. Instruments have been provided and even the personnel may have been improved.

In well organized plants, particularly where a comparatively large number of boilers of relatively low capacity are provided, complete control equipment may not be justified. Such is the case in the Colfax plant of the Duquesne Light Company.

The first 14 boilers at Colfax station which were installed in 1920 and 1922 have a maximum steam-generating capacity of about 140,000 pounds per hour, each. They are equipped with underfeed stokers. Forced air is supplied from a common duct and natural stack draft is provided. The steam output from these boilers is automatically regulated by controlling the forced-draft fans and the stack dampers.

When these boiler units were constructed, it was accepted practice to control the flow of air and gas automatically and to leave the stoker speed to manual control. As improvements have been made in control equipment, conditions at Colfax have been analyzed to determine whether provision should be made to control the stokers automatically. At no time have we been able to show that automatic control of the stoker speeds could be justified on the basis of increasing thermal economy, because of the small margin between the actual results obtained and those theoretically possible.

When the capacity of the Colfax plant was increased in 1924 by the installation of five pulverized-coal units, each having a maximum steam-generating capacity of approximately 220,000 pounds per hour; and again in 1927 by the addition of three similar pulverized-coal

units, each with a maximum capacity of 330,000 pounds per hour, careful consideration was given to the use of automatic combustion control. A study of the probable loading of these boilers showed that there would be no immediate demand for automatic control, because to gain the maximum benefit from the higher economy of these boilers, it would be necessary to operate them at constant output and take the swings in load on the stoker boilers.

In 1924 it was anticipated that automatic control of the pulverized-fuel-burning boilers at Colfax would be desirable at some future date, when extensions to the generating capacity of the power system would be made. With this in view one of the boilers installed in 1924 was equipped with complete Bailey automatic control to gain experience in its use. No operating benefit was derived from this equipment until 1930 when the base load for the system was shifted from Colfax to the James H. Reed station. This made it desirable to bank the stoker-fired boilers on off-peak loads and place the burden of control on the powdered-coal-fired boilers. The variations in load are sometimes too great for one boiler to handle effectively which may make the installation of additional control equipment desirable in the future.

The steam-generating capacity per boiler unit is the greatest single factor in making automatic combustion control economically possible, because the total cost of control equipment varies in almost direct proportion to the number of boiler units so equipped. Thus the percentage of improvement in thermal economy necessary to justify the cost of the control equipment is reduced. Furthermore, to make hand control physically possible, large boilers have to be equipped with remotely controlled power units for the operation of dampers, etc. The additional cost of providing automatic control is, therefore, correspondingly reduced. Another factor of more or less importance, depending upon the variations in steam demand, is the inherent poor regulation of boiler units of high capacity because of the small ratio of heat storage in the water to the boiler output. Increases in the demand for steam or, in other words, heat, are first supplied by heat stored in the boiler water and later from the fuel as the combustion rate is adjusted. Conversely, decreases in demand by the prime mover must result in the storage of heat in the water until the combustion rate is adjusted downward. The steam

pressure will, therefore, vary much faster in plants having a small ratio of water storage capacity in the boilers to steam generation, than in plants where a relatively large quantity of water is stored.

The boilers in the James H. Reed station are equipped with full automatic combustion control. Conditions here were favorable to automatic control because of the relatively small cost of applying automatic regulation to the equipment which would necessarily have been installed for manual regulation of forced- and induced-draft fans and dampers. Although this plant carries a base load, there are small fluctuations in the steam demand which, because of the small ratio of water stored in the boilers to steam output, require prompt adjustment of the fuel and air supply.

We do not credit automatic control with any saving in operating labor, because the number of operators required for the safe operation of the boiler plant can usually take care of hand regulation of the boilers. Automatic combustion control equipment will, however, relieve them of the machine-like task of regulation and enable them to apply their energies to better advantage with a possible resultant increase in economy.

The possible gain in the capacity of boilers due to the installation of automatic combustion control in well operated hand-regulated plants is of relatively small importance when it comes to justifying the cost of control equipment.

Our experience indicates that there will be no appreciable increase in the length of time that a boiler can be kept in service by the application of automatic combustion control. In most cases boilers have been removed from service for repairs to the boiler proper or to repair the accessory equipment not connected with the furnace. It is obvious that automatic combustion control would not affect outages of this nature.

Whether or not there will be any appreciable increase in the return on capital invested in boiler equipment by the use of automatic control depends entirely upon the loading of the equipment. Our experience at Colfax, as has been previously mentioned, has shown that the maximum overall plant economy was obtained by operating the pulverized-fuel units at constant ratings and placing the burden of regulation on the less efficient stoker-fired units.

J. E. THOMAS:* I have a few remarks in connection with automatic regulation without specific reference to any particular type or specific installation. We have a type of automatic regulation in our Springdale station. It is not the elaborate type described in these two papers. It is a type that we have adapted to our particular installation and we believe that from the economic standpoint it is about as far as we can go in automatic regulation at the present time.

Most of us remember the old hand-firing days in the boiler room when the most important job was to shovel sufficient coal into the furnace to keep up the steam pressure with little thought of efficiency. The fireman had to be a husky man—all he knew was to shovel coal and ashes. It was a back-breaking job and the more intelligent men would not take it. The boss fireman was a driver, and he drove.

With the introduction of the stoker-fired and pulverized-fuel-fired boiler the husky disappeared. He could not comprehend the new problems which arose. A higher grade of man was necessary. Brain had to be substituted for brawn. The result was a material improvement in boiler-plant operation and efficiency. The better educated fireman could learn to fire the boilers scientifically and, while it was necessary to train him for his new duties, he possessed the ability to advance under such a training. He was handicapped, however, because instruments were not available to give him a sufficiently continuous indication of what he was doing. Manufacturers of boiler instruments have made some rapid advances but even to-day there is a decided lack of instruments to guide the fireman properly. This applies to installations with or without automatic combustion control. I believe that there should be proper instruments for the fireman to tell whether there is sufficient air for proper combustion and whether there is a high loss to the ash-pit. How many stations to-day know the amount of combustible lost to the ash-pit of each boiler?

However, even with the introduction of stokers and pulverized fuel, the operator is closely tied down watching the water and fire and regulating both of them to take care of load variation as best he can, so that he has very little time to devote to the more scientific problems of efficient fuel combustion. The automatic combustion con-

*General Superintendent of Power, West Penn Power Co., Pittsburgh.

trol relieves the operator of this mechanical part of his work, and, as one of the papers states, it does just what the efficient fireman would do, but because it does it more consistently it makes a better job of it. It detects the slightest change in the steam pressure and corrects for it and then brings the combustion process into an efficient balance under the new conditions.

The introduction of automatic combustion control allowed the fireman to go one step farther in his development. It allows him to devote most of his time to studying the special conditions which are continually arising in proper combustion of fuel. Automatic control, being mechanical, can not reason, and even with the most complicated form of control with which I am familiar there is still lots of chance for the fireman to exercise his ability in the direction of improving efficiencies. The combustion regulators seem almost human but still they are mechanical and being mechanical they do only what they are told to do in advance. Sometimes we fail to plan ahead for all changing conditions and here is where the fireman's skill comes in.

There are three stages of automatic boiler regulation in use to-day:

Automatic over-fire draft control.
Semi-automatic combustion control.
Full-automatic combustion control.

The first stage, automatic over-fire draft control, maintains a uniform predetermined pressure in the furnace regardless of load conditions. In the second stage, steam pressure changes are corrected for by varying the air supply, leaving to the fireman the adjustments necessary to produce efficient combustion under the changing conditions. The third stage combines the first and second stages and, in addition, adjusts the furnace conditions, air and fuel supply, to produce efficient combustion under the varying steam demands.

The systems described in the papers presented to-day are full automatic combustion control, and without doubt full automatic control is capable of doing the most complete job while the first two stages go only part way. There are cases, however, where the economics of the problem may not justify a complete installation. I believe that the systems we have heard described are all capable of doing a good job and the particular type used will probably be the one which fits in best with the local conditions.

I do not believe, however, that the art of regulation has advanced as far in the boiler room as it has in the turbine room. Frequency control, proportional step loading of turbines (that is, dividing the load between the units on the maximum efficiency basis), maintenance of heat balance, and other problems in the turbine room are regulated to a degree of accuracy that is greater than used in any form of boiler regulation of which I know. I am not familiar with any combustion control, for instance, that automatically varies the load on the various boilers on the basis of maximum efficiency of the entire boiler room.

Most combustion regulators are sensitive to changes in steam pressure. Such a change causes the regulator to send out a message to all boilers under regulator control for a change in output. This might be all right if all the boilers were of the same design and the same condition of cleanliness, were operating at the same percentage of load, and had the same fuel conditions. This is seldom the case. It may be more efficient to take all the load changes on a few of the boilers over a given range and on other boilers over some other range. With hand control, the combustion engineer divides the load among the boilers on the basis of a predetermined loading schedule based on the existing conditions. This gives an overall efficiency higher than a uniform loading of all boilers. Hand distribution of load combined with automatic boiler regulation is, of course, possible, but I believe an automatic distribution of load on such a basis would be more efficient.

Such regulation is obtainable in turbine room loading and is in actual service with very good results.

A paper* presented last year by Mr. T. E. Purcell of the Duquesne Light Company and Mr. C. A. Powel of the Westinghouse Electric and Manufacturing Company on the subject of "Tie-Line Control of Interconnected Networks" describes this form of turbine regulation. By this method, load is distributed automatically among the various turbines to give the maximum efficiency at all loads. Any load change is automatically assigned to the turbine which can take care of the change most efficiently.

One of the papers at this meeting mentions light load periods, when instead of banking boilers the load is automatically reduced on

*Trans. A. I. E. E., v. 51, no. 1, p. 40.

all of the boilers in service. Our experience would seem to indicate that it is not efficient to operate a boiler below a certain rating and that under light load conditions some of the boilers should be banked rather than all the boilers operated at reduced load.

While automatic combustion control has done a good job, it can go farther and eventually it will cover this phase of the problem, I am sure. In the meantime a combination of automatic combustion control supplemented by a wide-awake, well organized operating crew can produce results far ahead of any completely hand-operated station, but it is essential that the operator have the proper instruments to guide him.

In the modern power-station large amounts of money are spent to make it possible to attain the highest efficiency. If these savings are to be realized in actual operation, it is necessary to keep the operating conditions as near to the designed conditions as possible at all times, throughout the complete operating cycle. For instance, steam pressures, superheat, turbine extraction, reheat cycle, and unit loading of boilers, turbines and auxiliaries must be watched at all times. This becomes a routine job and some of it, at least, can best be done by automatic control.

It is interesting to note that under the present conditions, when new construction work is not active, and when operators and designing engineers are looking for additional economy obtainable without large expenditures, automatic control comes to the foreground. Aside from the improved efficiency obtainable with automatic regulation other economies and improved operation are obtainable and I know of at least one central station where automatic regulation is now being installed even though the station is practically shut down, being used only as a stand-by for water-power generation and transmission.

It is well worth while for all of us who are designing and operating engineers to make a careful study of our existing and proposed stations to see whether automatic combustion control is warranted for our conditions. It is an economic study and should be treated as such, taking into account all the factors involved.

P. S. Dickey:* Mr. Boynton has described a very ingenious device which, if I am not mistaken, was developed in Germany a few years ago. However, by stressing the simplicity of this device I think

*Research Engineer, Bailey Meter Co., Cleveland.

he has been a little unfair to other manufacturers since he has shown only an individual regulator and not a system of combustion control. In the ten years during which we have been in the combustion control field, approximately five years were occupied in perfecting regulatory devices and since that time we have been studying proper applications of the control equipment. The application of the regulator to the system to be controlled is equally as important as the design of the regulating device.

We are open minded as to the relative merits of electrical and hydraulic apparatus. We are using both types and find that each offers advantages for certain applications. If the selective devices and power units are properly designed, either system will function satisfactorily. Both systems require adequate metering devices and both are dependent, to a certain extent, upon the possibility of controlling the boiler auxiliaries.

Referring to Mr. Wilhoite's discussion, it is generally agreed between makers and users of automatic control systems that automatic control can do no more than a competent operator can accomplish if provision is made for suitable metering and remote control.

Regarding the matter of anticipation, it is possible, in certain cases, for an operator to anticipate load changes, both as to magnitude and time, before the change in load actually takes place. This is true in utility plants where the load curve is reasonably consistent from day to day, and it is not unusual to find the operators changing the supply of fuel, air, and water before the normal load change takes place. It is not possible for the automatic control system to accomplish this result, nor is it necessary with the present-day boiler design. The boilers are equipped with an accumulator for storage of both heat and water-supply, and as long as the boiler pressure and boiler water-level are maintained within reasonable limits it is not unwise to capitalize on the investment in the boiler drum to take advantage of the accumulator which it provides. The short period of time during which the water and heat are drawn from or accumulated in the boiler drum is ample for the control to make the necessary changes and for the combustion and feed-water systems to accelerate or retard to the correct value, so that there is no necessity for changes in combustion rate or water flow before the change in load actually takes place.

I was very much interested in Mr. Wilhoite's statement that it is necessary to equip all automatic control systems with provision for reverting to manual control due to the limited range of operation. We are heartily in agreement with this statement, but hope that every one realizes that the range of operation is limited not by the control apparatus, but by the auxiliary equipment under control. Boilers seldom are equipped with draft and combustion equipment which has a range of operation corresponding to the range over which the boiler is finally operated, and special combinations of fan and damper control of the draft and of the fuel-burning and fuel-feeding equipment are necessary. The simplicity of the automatic control equipment bears a direct relation to the range of operation of the boiler auxiliaries.

It is very difficult to give figures showing the savings which can be accomplished through the addition of automatic control. It would be very difficult to find two plants having similar equipment and operating under comparable conditions. It would be practically impossible to operate the larger modern boilers without some sort of remote control of the auxiliaries, and it would likewise be impossible to maintain any reasonable efficiency of operation if adequate metering devices were not provided. The actual cost of providing automatic control after providing the necessary equipment for metering and remote control is not great, and can therefore be readily justified since it makes certain that the proper operating conditions as indicated by the metering devices will be maintained.

Mr. Wilhoite brings up the point that in measuring air flow by means of the differential pressure across a portion of the boiler passage, certain precautions are necessary in order to insure accuracy. We agree, and contend that in adjusting the relationship between steam flow and air flow of the Bailey boiler meter we have been following a procedure which assures accuracy except under most unusual circumstances. The boiler meter remains the most accurate and most reliable combustion guide available to-day.

Regarding the three-element feed-water control, Mr. Wilhoite can be assured that dependable equipment of this type is now available. We have an installation on the west coast where load changes from 10 per cent. to approximately 75 per cent. of plant capacity are made instantaneously, and the operation of the three-element, feed-

water control on the high-pressure boilers is most satisfactory under these circumstances.

The following safeguards and protections have been included in the three-element, feed-water control system:

1. Both high and low water-level alarms are provided.

2. Failure of the power supply will cause the valve to be locked at the position existing at the time the failure occurred and will cause the necessary alarms and signal devices to be operated.

3. Manual control of the feed-water valve is possible at times of power failure.

We believe the above precautions are ample for safe operation and feel that other provisions would complicate the control unnecessarily.

We thank Mr. Griffin for bringing out a most interesting point. We can only sell regulating devices and try to make an intelligent application of the control apparatus. There are, however, a great many things which we can not foresee, and the plant designer is equally responsible for proper selection of control equipment which will satisfy the conditions of his particular plant. There is often a tendency to place responsibility on the control equipment where plant conditions are entirely different from those contemplated in the original design. It is only through co-operation of the designer and operator of the plant and the manufacturer of the control that the maximum benefits may be achieved.

Mr. Thomas brings up the matter of boiler loading. I wonder if there will really be a demand for a scheme of load proportioning of boilers in view of the present trend toward single boiler-turbine units. With the advent of water-cooled furnace walls and improvements in coal-burning equipment, boiler availability is approaching that of the turbine, and the necessity for a large number of boilers is gone. The necessity for load proportioning between boilers is gone when only one boiler feeds each turbine. Even in existing plants one must balance the expense of control for boiler load proportioning and the complication of such equipment against the benefits which may be derived therefrom.

C. J. King:* Practically all of the criticisms have been most ably answered by Mr. Bailey's representative Mr. P. S. Dickey and I wish to indorse his discussion. Particularly do I agree with him in his reference to the inability of the control manufacturer to build machines with steel or cast-iron brains. That is not being done and probably never will be. We look upon control apparatus rather as a tool, the intelligent use of which by the operator produces definite results. A highly skilled operator can frequently do a rather good job without these tools, but invariably a good operating engineer provided with good tools can do an infinitely better job than without such equipment.

There is one point, however, on which I disagree with Mr. Dickey greatly; that is, where he concludes that both hydraulic and electric drive can be used with equal effectiveness. For the bulk of our boiler plant regulation, as well as all important individual regulating problems, we have stuck to the hydraulic equipment because it has inherently a variable rate of response. The motor has one rate of response. It is geared to the damper shaft or fan vanes and can respond at only one speed. Our hydraulic equipment does not respond that way at all. It reacts at a rate of speed proportional to the rapidity or magnitude of the load change. If a large load change is needed, a great and rapid change in the control of the fans and other fuel input auxiliaries is immediately produced by the true regulator with hydraulic power. Such flexibility of response can not be obtained by the one-speed, geared actuator.

The point made by Mr. Wilhoite relative to the drop across a variable orifice for regulating purposes happens to refer to our type of gas-metering control. We used the drop across a variable orifice only to obtain a wide range of volumetric control. The drop across a fixed orifice is considered the conventional way to measure flow-regulating problems of this nature but in this case we are limited to a four to one flow range within the regulating accuracy range of a gas-volume regulator. A 16 to 1 flow change is about the range of most of our regulators used in these gas-mixing jobs. To accommodate this wide range, we use a variable orifice and have found it makes no difference whether it is of the sliding-vane type, the shutter type, or the ordinary butterfly valve. It is not exactly an ordinary

*Smoot Engineering Corporation, New York.

butterfly valve, however, as we in reality use a specially designed valve, with a clapper having definite stream-flow characteristics. A careful study of the velocity and static connections across the valve has been made, giving to the valve extremely accurate regulating characteristics for these gas-mixing controls.

The contribution by Mr. Thomas discloses a complete understanding of the system we have endeavored to show. With reference to his remarks regarding the control of the relative steaming rate from one boiler to another to take advantage of the most efficient operating point for each boiler, I want to state that this feature can be obtained with the type of control we use.

The same type of ratio-adjusting device used to control the ratio of fuel and air to the individual furnace is used on the station "supermaster" to control the ratio of one boiler's steaming output to another. Furthermore, any one boiler may be fixed at its most efficient point of steam generation independently of the remaining boilers. The ratio of steaming output from one boiler unit to another, is decided upon entirely from operating practice which discloses the most efficient relationship to use. Complete flexibility in the use of this feature is provided. This plan has been in use in quite a number of boiler plants but was not mentioned in my paper at this meeting.

One speaker referred to the other possible applications of regulators of this type and particular reference was made to the adaptability of such equipment to frequency control. The very same type of hydraulic speed governor used in our fuel feeder and stoker-speed control for boilers has successfully been applied to frequency regulation. We have recently made such an installation where this regulator automatically controls the 25-cycle frequency to within a total variation of ± 0.01 of one cycle in spite of a typical fluctuating paper-mill load.

This matter could easily become the subject of an entire meeting as each one of the almost endless array of regulating problems presents in itself a most interesting story. Of particular interest in this district, is the extensive regulating work done by the Smoot Engineering Corporation in the gas-mixing field where city consumption of mixed natural and manufactured gas is rapidly becoming commercial.

In the steel plant, this type of gas mixing has been in regular use since 1927 and has resulted in tremendous savings in coke-oven gas or other manufactured gas, because of the effective use of our gas mixers in utilizing the relatively low B.t.u. blast-furnace gas as a base for the mixed gas.

T. E. PURCELL, *Chairman:* It is too bad that we have not heard more of the economics of this work, cost of installation, cost of operation, how much can be saved by using it, etc. That is what the user wants to know first of all, for he must justify the expenditure.

AUTOMATIC COMBUSTION CONTROL ON STEEL-MILL BOILERS*

By T. A. Peebles† and G. W. Smith‡

The modern boiler plant, whether, it be large or small, contains a few pieces of equipment that are absolutely necessary to the generation of steam, and a number of others that are not necessary, but which are desirable in varying degrees. An engineer need not be an old timer to remember clearly boiler plants consisting of nothing but boilers, feed pumps, chimney, and coal scoops and it can not be denied that these plants delivered the goods. It can therefore be argued that all other boiler-plant equipment is unnecessary.

There is probably no engineering problem that has received more concentrated attention in the past twenty-five years than that of reducing the cost of steam generation. The result has been the development of various devices for economizing in fuel and labor. Some of these devices have achieved temporary popularity only to be replaced by others as the art developed. The fact that combustion control equipment has steadily gained in popularity is evidence that it has made a real contribution to economy in steam generation.

The reasons for this are apparent from a consideration of the operating problems involved. In order to produce the maximum quantity of steam from a given amount of fuel it is necessary that the ingredients entering into the combustion process be delivered to the furnace in their proper proportions, and in order that the steam produced shall have maximum value (uniform pressure and temperature) it is necessary that the fuel and air be delivered to the steam generator in proportion to the demand for steam.

In order to obtain these results, a number of related variables must be maintained continuously at their proper relative values, and this becomes a difficult task if an operator is required to take care of more than one modern steam-generating unit. In order to change from one rate of steam generation to another it is necessary to adjust the draft capacity of the fan or chimney which involves the adjustment of a damper position, or both a fan speed and a damper position;

*Presented October 4, 1932. Received for publication January 10, 1933.
†Vice-President, Hagan Corporation, Pittsburgh.
‡General Manager, Hagan Corporation, Pittsburgh.

also to adjust the forced draft a corresponding amount which in most cases involves the adjustment of both a fan speed and a damper position; and finally to alter the fuel feed to bear the correct relation to the new air flow.

All of these adjustments should be made as nearly as possible at the same time and in proportion to the change in load. If this is to be done manually with even a reasonable degree of accuracy, it is necessary that all manual controls be brought to a central point and operated by means of push-button or relay devices, suitable indicators being supplied to show the operator the conditions he has established by means of these manual adjustments. This involves the use of pilot-motor-operated controllers with remote push-button adjustments, suitable power-operating devices for dampers, and means for remote control of fuel-feeding devices, all with corresponding indicating devices at the panel. Such equipment is a necessity if the operator is to be provided with means for performing even a fair job of hand control, and, when a system of this kind has been installed, it will be found that the cost closely approaches the cost of a completely automatic control system. In considering the economics of combustion control its cost and results should be compared, not with a plant devoid of all means for manual control, but with a plant including the necessary remote-control devices for manual operation. When a comparison is made on this basis, it will be found that a control system will usually pay for itself in a few months.

In order to realize the advantages of automatic over manual control it is only necessary to consider the operating characteristics of the steam-generating equipment and to consider the rate and extent of load changes that may occur. A large percentage of the total heat absorbed by a steam-generating unit is taken up by the heat-absorbing surfaces that are exposed to direct radiation from the furnace. Air entering the fuel bed of a stoker or the air passages of a burner for gas, oil or pulverized fuel, will enter into the combustion process and the resulting gases will pass beyond the heating surface adjacent to the furnace within two or three seconds time. It follows, therefore, that the heat absorption of the boiler follows a change of heat liberation in the furnace almost instantly, and since there is little accumulator effect in a modern boiler, the time lag between a change in

combustion rate and the resultant change in rate of heat absorption is very short indeed.

The steam flow to engines or turbines is controlled by governors capable of very fast operation, and where steam is used in industrial processes the flow is often controlled by manual manipulation of quick-opening steam-valves. The steam-consuming units and processes are capable of changing their rate of steam consumption very rapidly, and the boiler response must be almost instantaneous or it would be impossible to carry varying loads without excessive pressure variations, unless a large accumulator were interposed between the boilers and the steam consumers.

A few years ago immediate response to load variation was not so necessary. Using the commonly accepted statement that some modern boilers contain as little as 0.25 pound of water per pound of steam generated hourly, simple calculation may be applied to show the rate of pressure change which follows the change in steam demand. Assume such a boiler operating near capacity at 385 pounds pressure and taking feed-water at 300 degrees F., and suddenly alter the load thereon by 25 per cent. Until the rate of heat absorption has been altered, the pressure will change approximately one pound per second. In 30 seconds the pressure will have changed 28 pounds. Some years ago when similar boilers contained more nearly one pound of water for each pound of steam per hour, the pressure change in 30 seconds would be well under ten pounds. This calculation ignores any concomitant disturbance in superheat.

It is clearly evident that upon rapid change in load, immediate change in rate of combustion must ensue.

Since the steam load imposed on boilers can, in fact, vary with great rapidity and since the boilers are capable of following this load, provided the necessary adjustments of fuel and air supply are made at the proper time and rate, the control equipment should be capable of rapid traverse through its range. At the same time it must be stable in operation to prevent "hunting," sensitive to small changes in load, and capable of making small adjustments to correct for small variations in load. All these things can be done more satisfactorily by mechanical means than by manual adjustment, since the various operations can be timed correctly and can be made to follow promptly both the rate and extent of the changes in load.

For any given plant load, the boiler capacity in service should be capable of handling this load at or near the most economic rate for the individual units. It is, of course, not always possible to operate boilers near their most efficient point of capacity on account of periodic load swings, but the operators can do a great deal to improve overall plant efficiencies by keeping in service the correct number of boilers. It follows, therefore, that the load should be divided in constant proportion among the boilers in service and, with identical boilers, should be divided equally. With automatic control a common impulse, variable in accordance with plant load, serves as the primary control impulse of all boilers, and therefore insures proper division of load among the boilers in service.

Fig. 1 shows the result of a test run to determine the accuracy with which the load is divided between the two units. It shows the relation between air flow and steam flow for each boiler, and the steam pressure and temperature at the throttle of the turbine. The results show an equality of load within the limits of accuracy of the metering equipment from which the records were taken.

The charts are taken from two stoker-fired boilers, the control of which is similar to that of the typical stoker installation described below. Identity of load variation is obtained by setting up identical air flows in accordance with the master impulse. The fuel-feeding rate is adjusted to that value which will, under these conditions, maintain uniform fuel beds.

The application of control equipment to the more common boiler, stoker, and pulverized-fuel-fired combinations is fairly well standardized by the different manufacturers. Many slight modifications are required to meet individual conditions, but the following types of control may be considered typical.

Fig. 2 shows the application of control to a number of boilers fired by underfeed stokers and equipped with variable speed forced- and induced-draft fans. The master controller responsive to steam pressure generates a control impulse which is relayed to each of the boiler control panels where it passes through individual boiler relays, which permit placing any boiler ahead of or behind the other boilers in the group, or placing it on manual control, if desired. The load control impulse leaving the boiler panel loads the uptake draft controller which maintains a relation between loading impulse and uptake draft

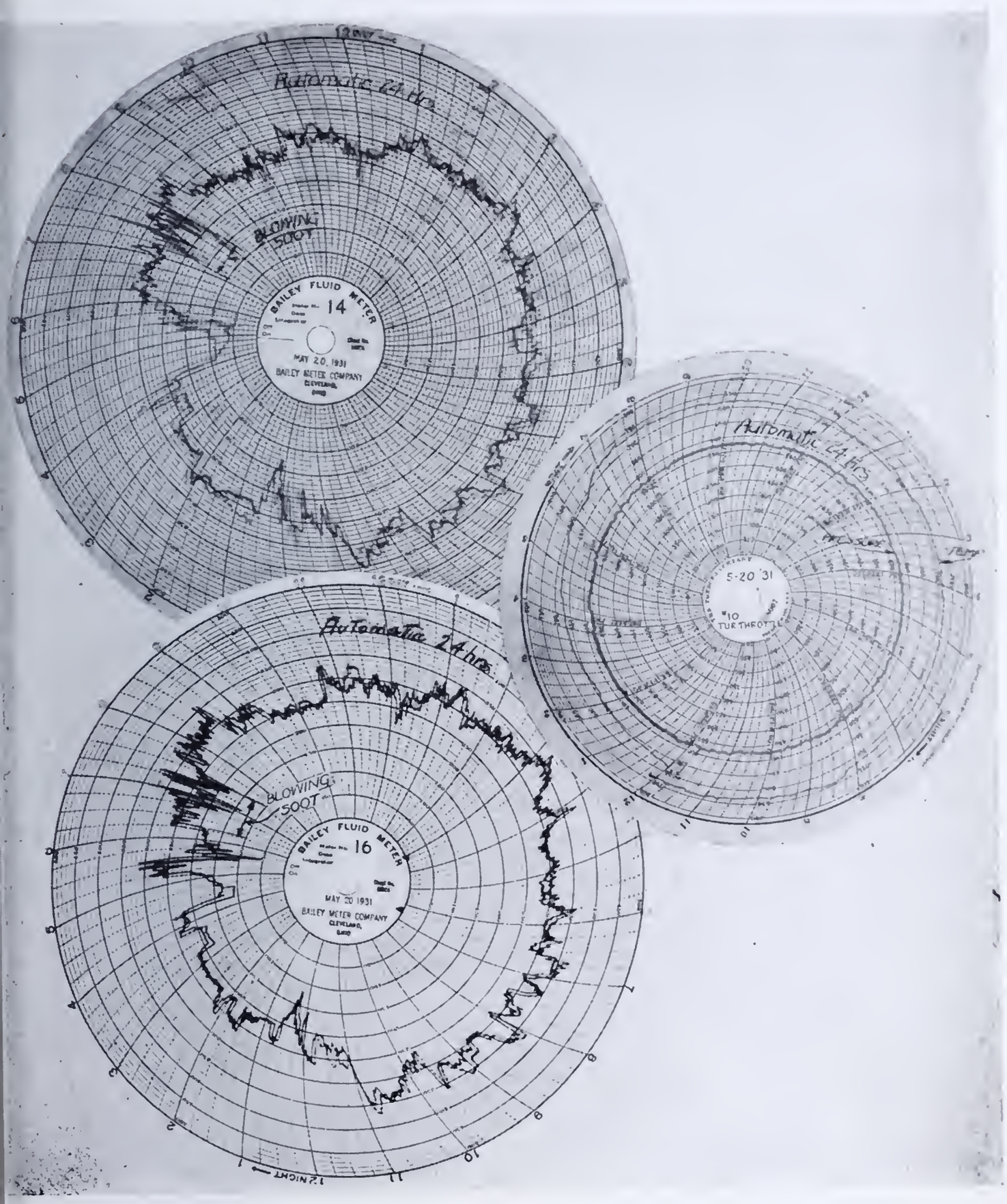

Fig. 1. Meter Charts Showing Distribution of Load between Two Boilers under Automatic Control.

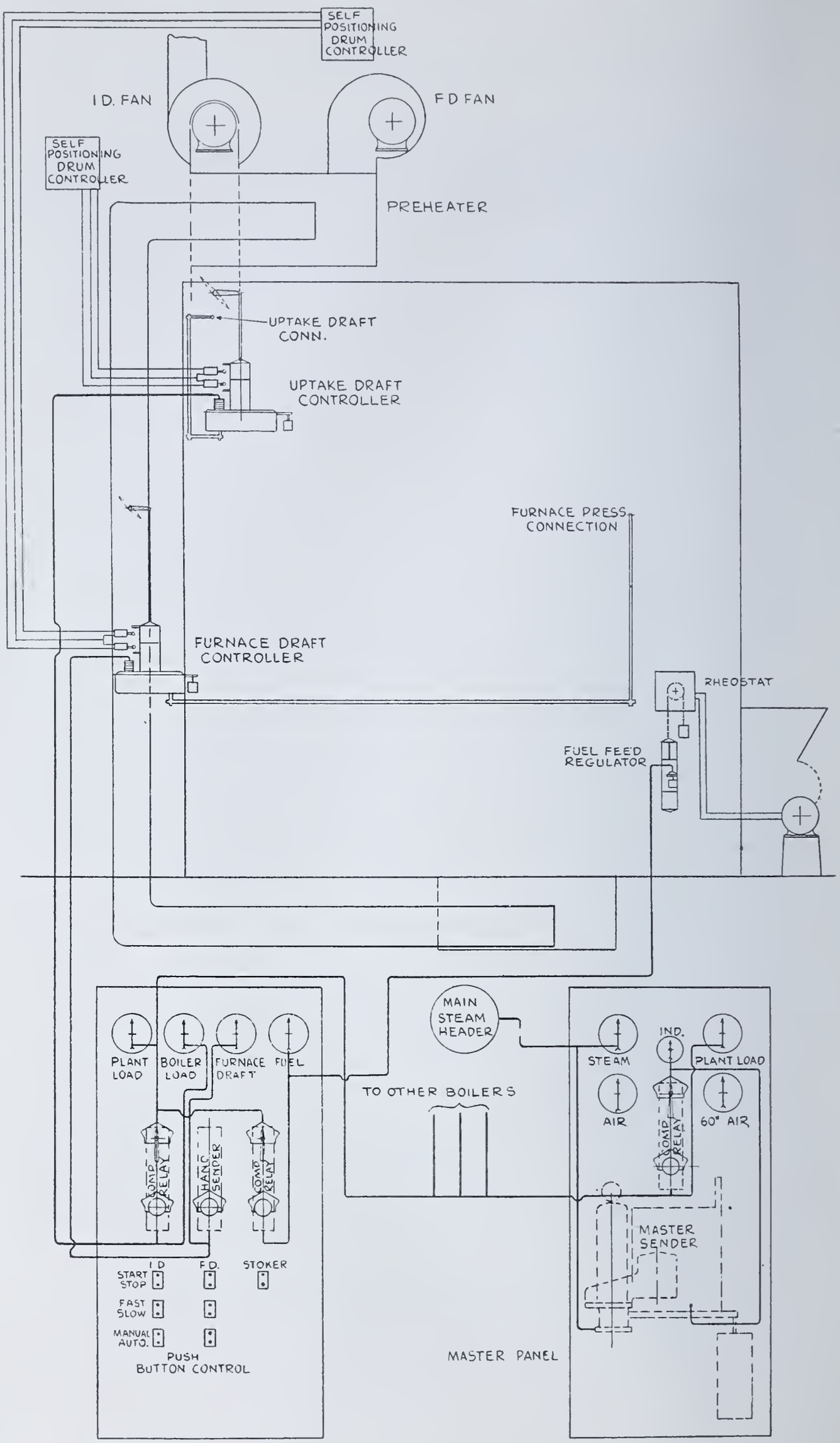

Fig. 2. Combustion Control Applied to Stoker-Fired Boilers.

by a combination of fan speed and damper position control. For small changes in load the damper position only is adjusted, while for larger changes the fan speed is changed and the damper automatically reset to that point required to give the desired draft with the altered fan speed.

Changes in uptake draft will produce corresponding changes in combustion-chamber pressure unless the forced-draft air supply is also adjusted. This is accomplished by a furnace draft controller, responsive to the draft in the combustion chamber and controlling the speed of the forced-draft fan and the position of the undergrate damper.

The stoker speed is controlled in accordance with uptake draft, either directly by use of a regulator responsive thereto, or indirectly by application of the master impulse, as shown in the figure. A regulator responding to the master impulse adjusts the field rheostat of the direct-current stoker motor. The movement of this type of regulator may be arbitrarily co-ordinated to master impulse to provide for varying excess-air requirements at different ratings. The same adjustment, as with some meter elements, compensates for departure of gas-flow draft-loss characteristic from the convenient formula $p = KV^2$, which is so commonly used and so often misused or perverted.

A combustion-control system for boilers burning only one fuel at a time need not be complicated. It is in fact quite simple. While simple in principle it may become complex in the actual application due to the nature of auxiliaries to be controlled. In many cases these auxiliaries are all chosen before consideration is given to the combustion control, and the selection probably made on the basis of cost and power consumption. It is usually possible to work out methods to control whatever auxiliaries will be available, but if these are selected after considering their adaptability to automatic control a simpler and more satisfactory installation will result.

A common form of auxiliary that involves the control engineer in difficulties is the four-speed stoker motor. The combination of a four-speed motor and two-speed gear-box makes possible a wide range of stoker speed by manual adjustment, but provides no suitable means by which a simple and effective automatic control may be applied. While there may be mechanical advantages in the use of a drive of

this kind, they are more than offset by the difficulty in attaining proper graduation of stoker speed to meet the varying load conditions, and the disadvantages considerably more than outweigh the considerations of cost and simplicity which often dictate the selection of this type of stoker drive.

The control of fan speeds often involves difficulty owing to the manner in which they are selected. The first step is to consider the total weight of air or gas to be handled and the differential that must be set up by the fan. Values considerably on the safe side are assumed both for air and gas weight and total resistance to be overcome. A fan is then selected of ample capacity to meet these requirements, and a standard motor of the horse-power next larger than the calculated power to drive the fan is selected. The final result is that with a boiler operating at maximum rating, the higher fan speeds may never be used, and, even if used, the power consumption is probably not more than 70 per cent. of full motor load. Since the resistance in the motor controllers is usually designed for full load conditions only a limited speed range of the fans is possible. To a large extent this condition is inescapable because certain allowances must be made for factors that can not be determined accurately and some margin of safety is desirable to take care of possible future changes in furnace construction or boiler baffling, as well as to assure meeting capacity guarantees on such equipment.

To insure satisfactory control in spite of these conditions, provision should always be made for suitable dampers, substantially mounted and conveniently located so that they can be operated to give regulation between the different points of fan speed control and at those ratings below which the minimum fan speeds provide excessive capacity.

The control equipment to operate these dampers should co-ordinate the speed of fan and position of damper so that the minimum loss of power occurs across the damper. The usual assumption is that at low fan speeds, that portion of the damper stroke used for regulation must be nearer the closed position than at higher speeds. Occasionally (but not usually) this assumption is incorrect and field adjustment must be made to attain the most economical operation. This is more likely to be the case where fans and motors are found to have excess capacity. Fig. 3 displays a family of curves showing

the co-ordination of fan and damper position predicted as desirable for an induced-draft fan installation. Curves numbered 1 to 13, inclusive, are segments of theoretical curves showing expected relationships between air flow and damper opening for each of the 13 motor speeds. The arrows show the desirable sequence of operations both on increasing and decreasing loads. The installation was designed to give such displacement of speed-changing contacts with altered speed of fans.

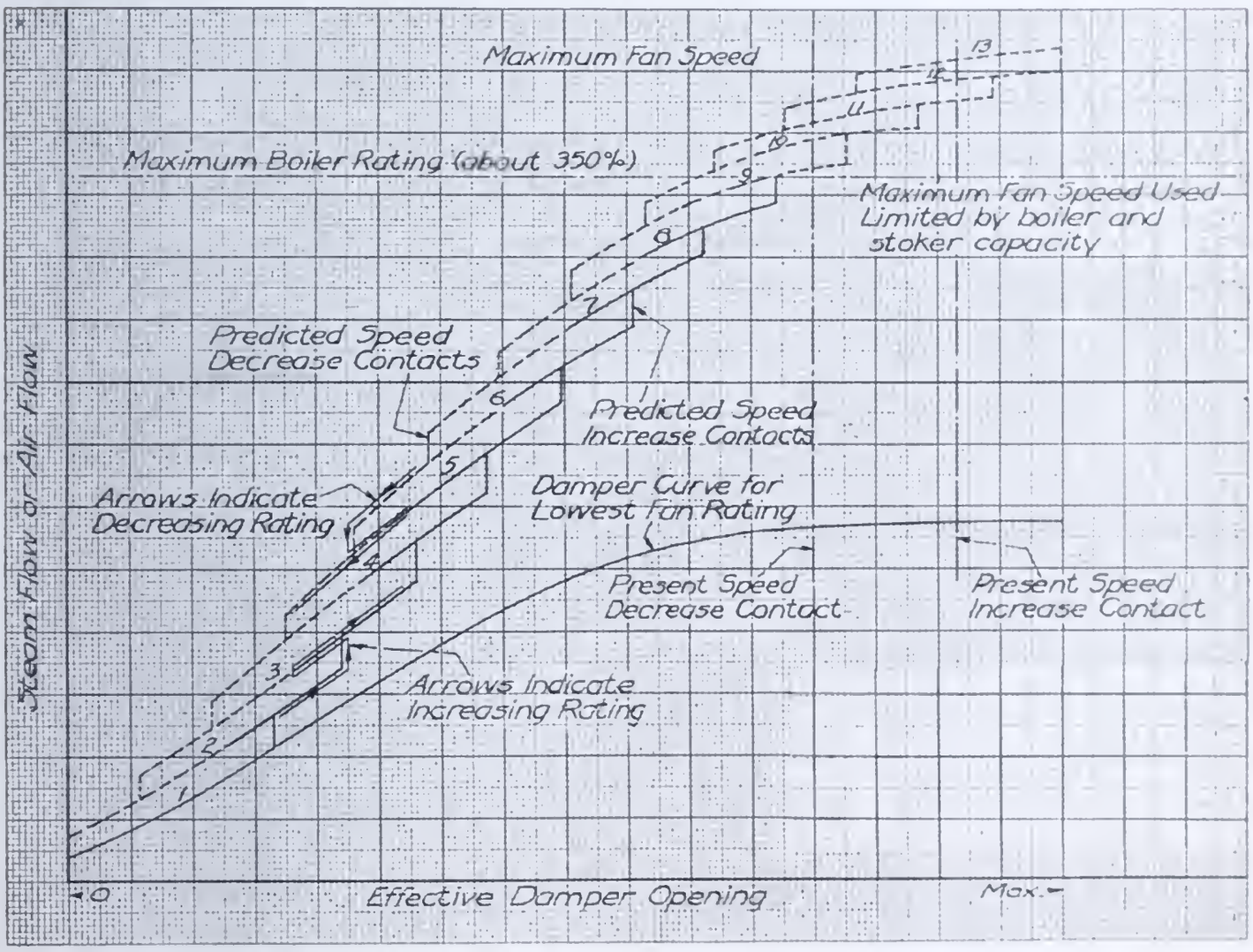

Fig. 3. Curves Showing Predicted Operating Sequence of Fan Speed and Damper-Control Equipment.

When placed in operation, it was found that the fan had excess capacity and only the nine lower speeds could be used. Furthermore, superior results were obtained by making all speed increases at one damper opening, and all speed decreases at another damper opening. This unexpected but not unprecedented result led to an investigation

of the correlation between air flow, damper opening, and fan speeds, and the results are shown in Fig. 4. The numbered curves again represent relationships for different fan speeds. The crosses and circles show the individual observations. A smooth increase in air flow was found to exist at all speed changes except for a hiatus between speeds one and two, amounting to less than 4 per cent. of maximum rating. Accurate non-hunting operation was had at all speed changes.

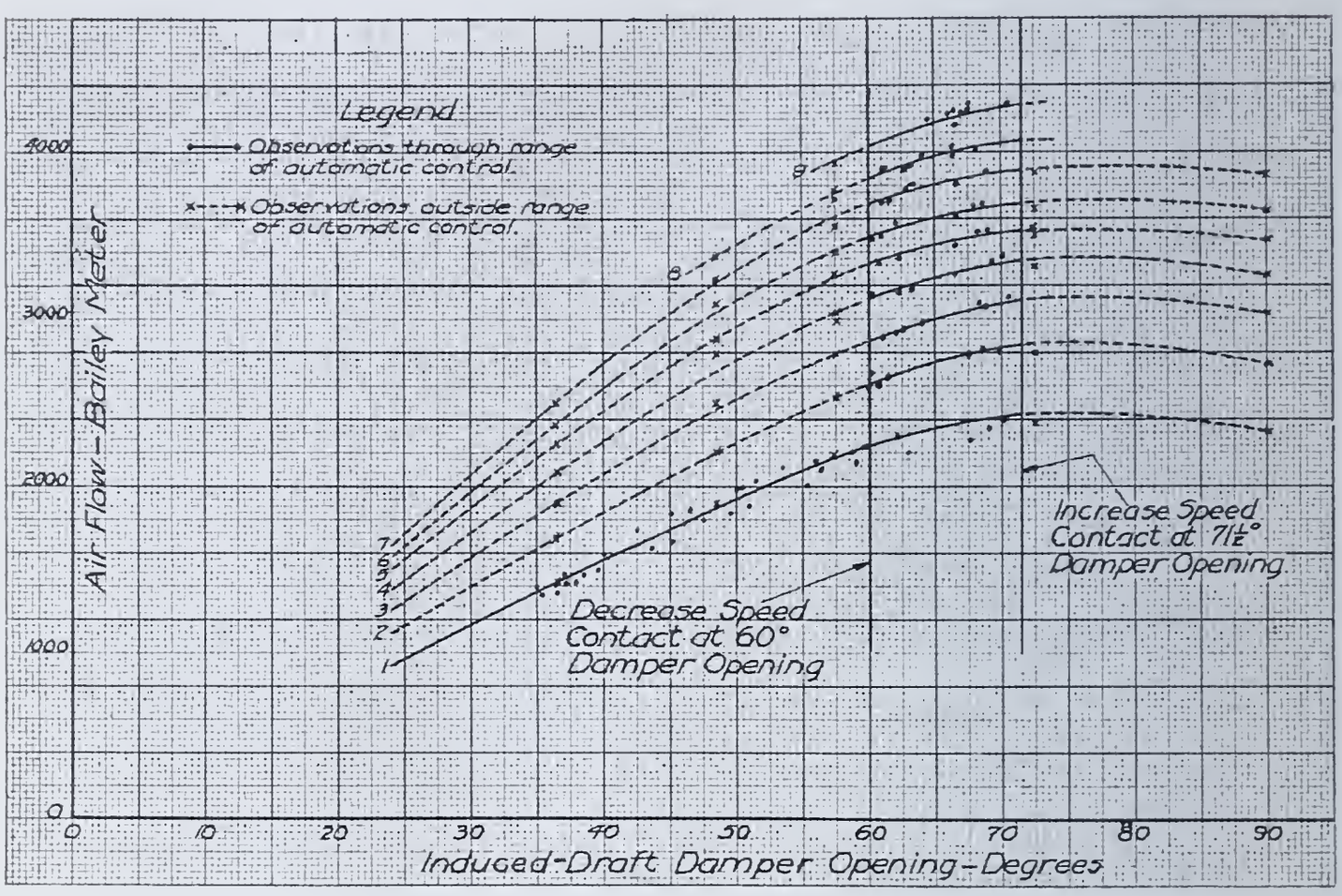

Fig. 4. Curves Showing Performance of Control Equipment for Induced-Draft Fan.

In arriving at these figures it was found impossible to take readings for extending the curves for fan speeds 8 and 9 to smaller damper openings because of motor overloading which occurred when this was attempted. This observation led to the preparation of Fig. 5 in which is plotted apparent differential across the induced-draft fan damper as a function of air flow. Here again the numbered curves represent different fan speeds. The trajectories thereof, which are marked in degrees, represent different damper openings. The heavy lines at the bottom show the path of march of the control as finally adjusted;

the heavy lines above, that which would have resulted from the expected adjustment in accordance with Fig. 3.

Fig. 6 is Fig. 5 redrawn to show contours of computed loss of electrical power across the regulating damper, under certain assumptions as to efficiency of fan and motor, and as to the significance of the negative differentials across the damper. The economy of the method of operation finally selected is manifest.

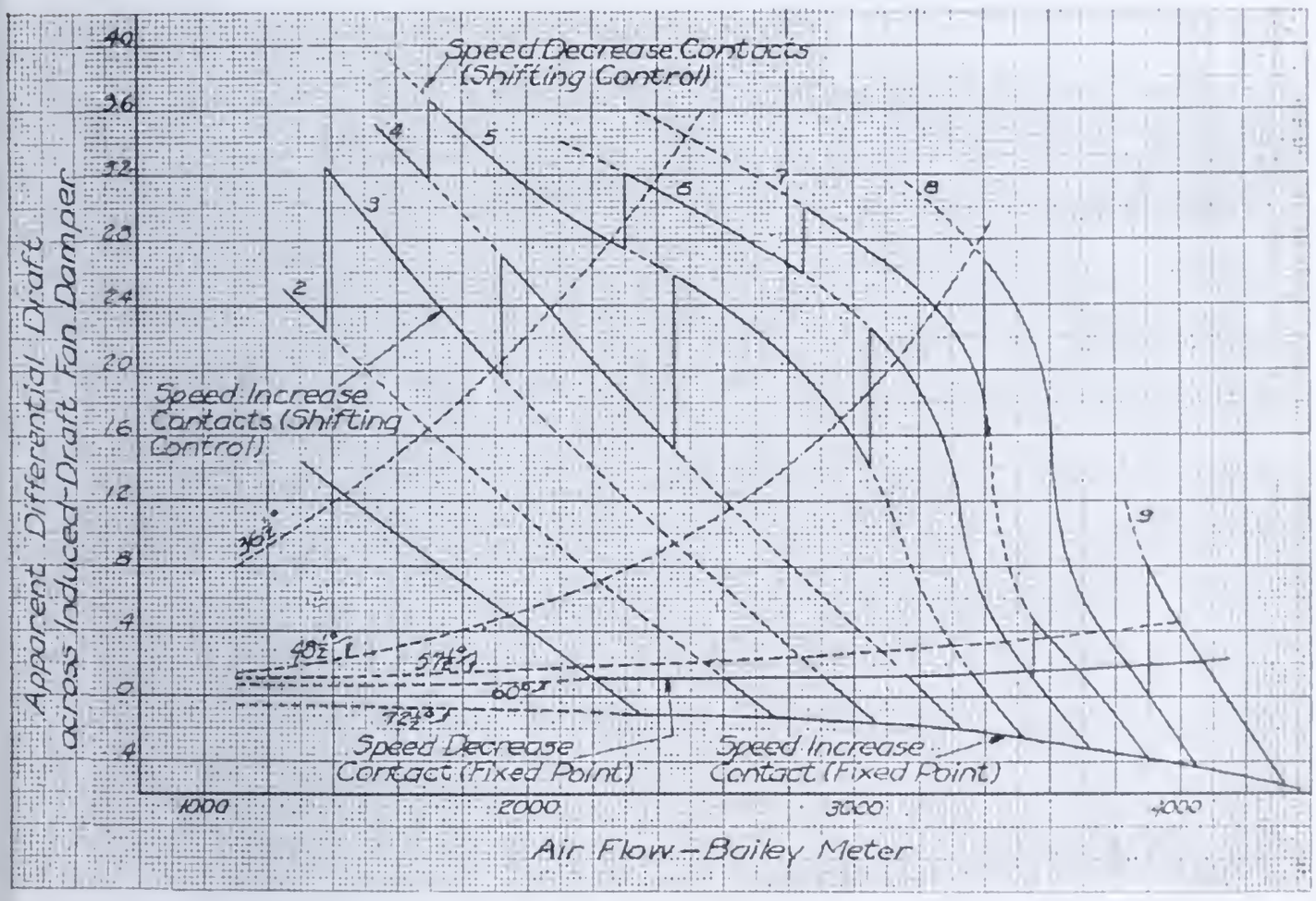

Fig. 5. Curves Showing Pressure Loss across Damper at Various Fan Speeds and Damper Openings.

While the conditions at this plant were uncommon, they demonstrate to a marked degree the field flexibility which must be expected of automatic regulating equipment. This need for flexibility exists not only as to draft-control equipment but with devices for fuel feed control as well.

The characteristics of stoker drives and certain types of mechanism for feeding pulverized fuel are such that only minor calibration of the control equipment is required. In other instances, the rate of

fuel feed is determined by the combined effect of a number of independently variable speeds or pressures between which constant proportionality is lacking. The design of the control system must in these cases adapt itself to the characteristics of the equipment controlled, as the proper operation of the fuel feed equipment, chosen for economy, can not be sacrificed.

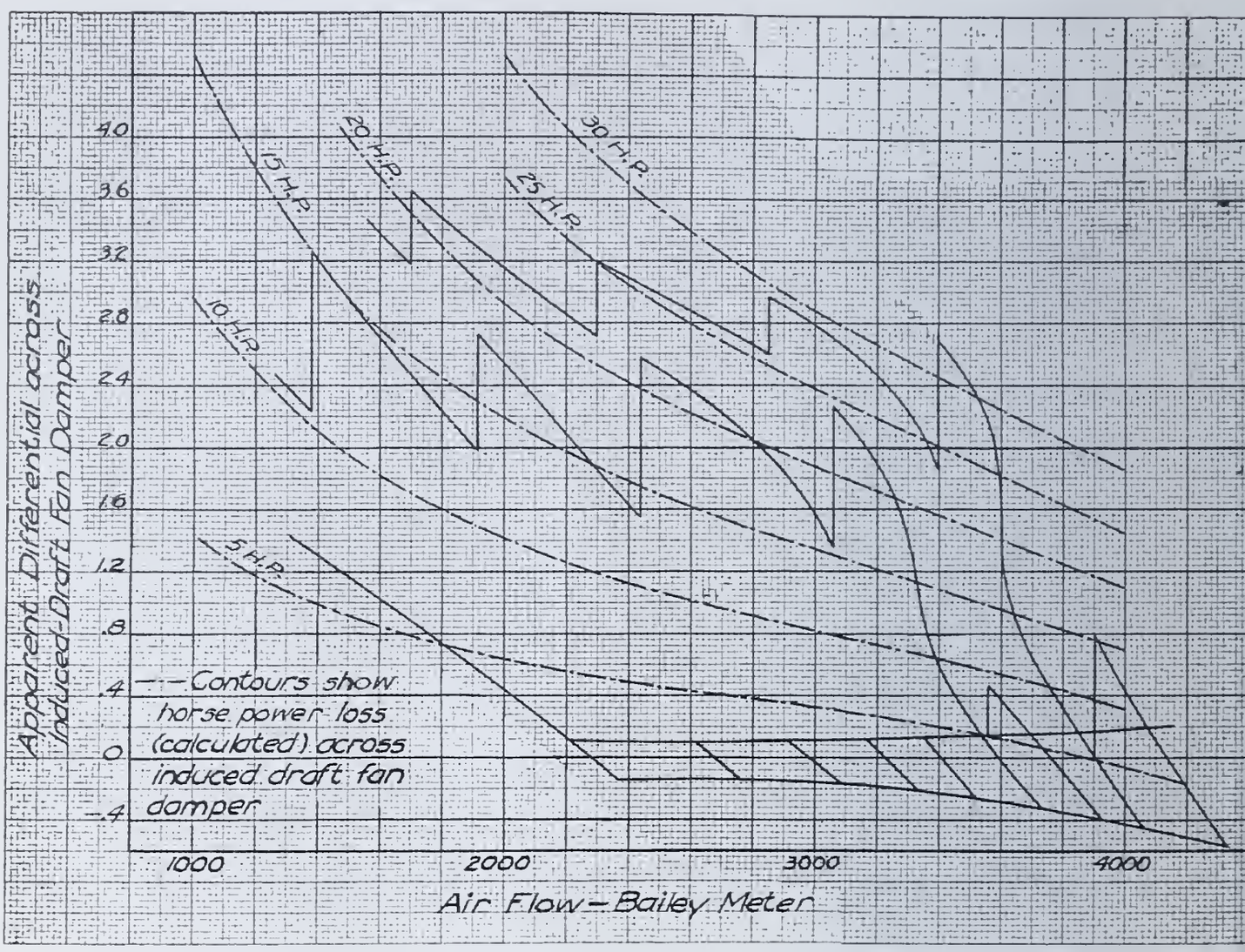

Fig. 6. Curves Showing Relative Power Losses across Damper at Various Fan Speeds and Damper Openings.

Fig. 7 shows the relationship desired between feeder speed, mill speed, exhauster speed, and secondary air pressure for a pulverizer supplying powdered coal for direct firing. These relationships were selected after extensive tests under manual control as representing the required operation for maximum efficiency. The control equipment was then adjusted to duplicate them exactly, provision being made for manual adjustment of air-fuel ratio.

Diagrams of a great diversity of types might be shown here to indicate an identity of control design for different kinds of fuel-burning equipment; for example, a lay-out for the control of equipment burning pulverized fuel duplicates exactly, as respects regulating equipment, that which has been shown in Fig. 2 for a stoker-fired boiler. It might at first appear that stoker firing, wherein minor or momentary inaccuracies of fuel-feeding rates are "averaged-out," differs basically in its control engineering from pulverized fuel firing, where such inaccuracies in air-fuel ratio, once committed, are there-

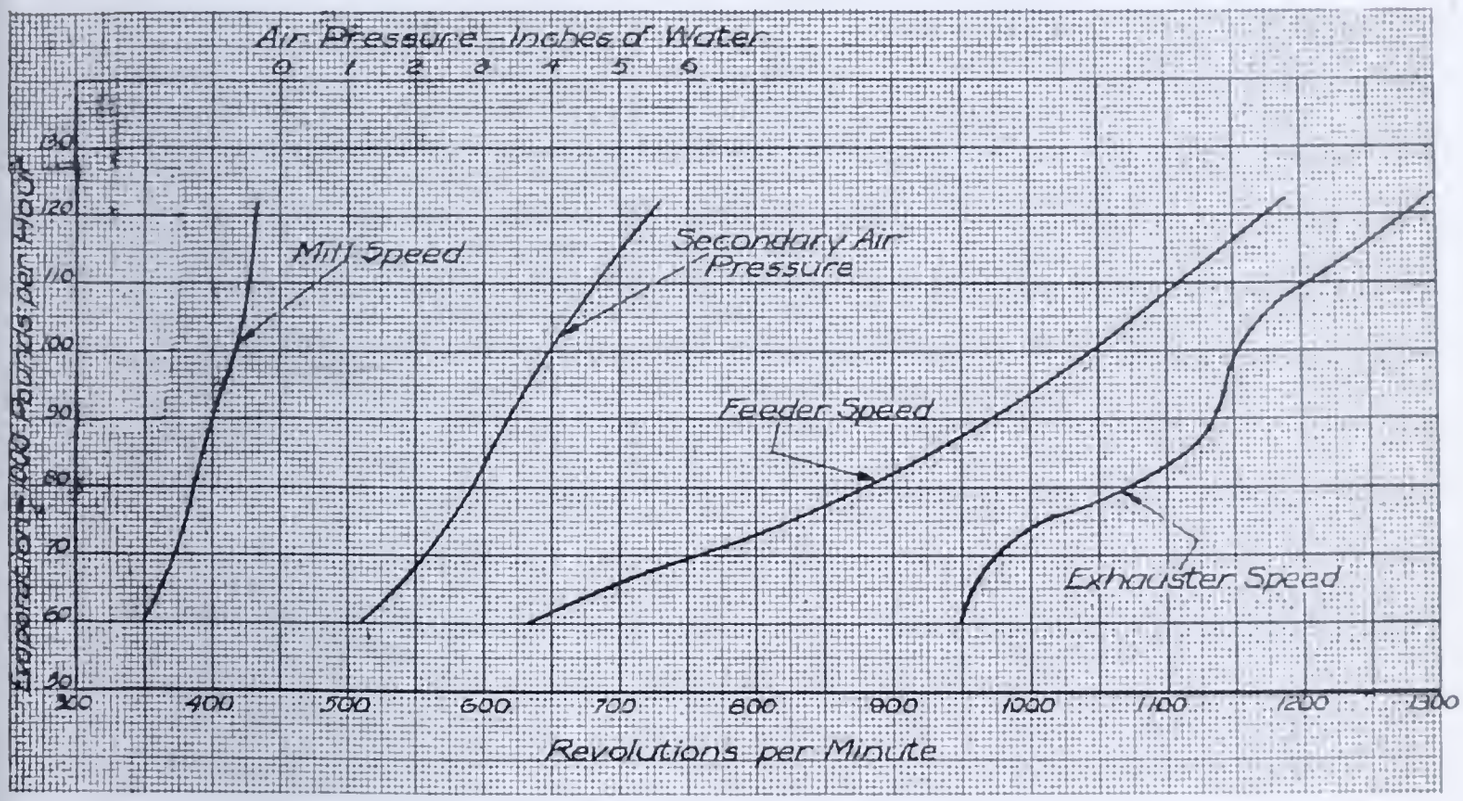

Fig. 7. Relationship between Operating Variables Affecting Air-Fuel Ratio at Different Rates of Boiler Output.

after irrevocable. This is not the case. Equipment suited for stokers is equally applicable to pulverizers, provided only that it is capable of a high order of accuracy at each successive moment.

Measurements of excess air, whether by one means or another, are properly a valuable independent standard of control performance; when to these are added determinations of combustible in flue-dust, properly interpreted, the degree of accuracy is complete. The first group of figures supplies the general outline of hour-to-hour performance; the second fills in the details of minute-to-minute accuracy. The superior efficiency of automatic as compared with manual control

in the modern high efficiency boiler plant is perhaps nowhere so manifest as in this particular. The use of automatic control should, and does, permit the maintenance of more uniform, and therefore lower, percentages of excess air, especially in large boilers having extensive water-cooling surface.

Despite the similarity of certain installations, no standardized mode of control is possible for all boilers, or even stokers, pulverizers, burners, and fans. Especially where more than one fuel is burned is multiplicity of control function necessary.

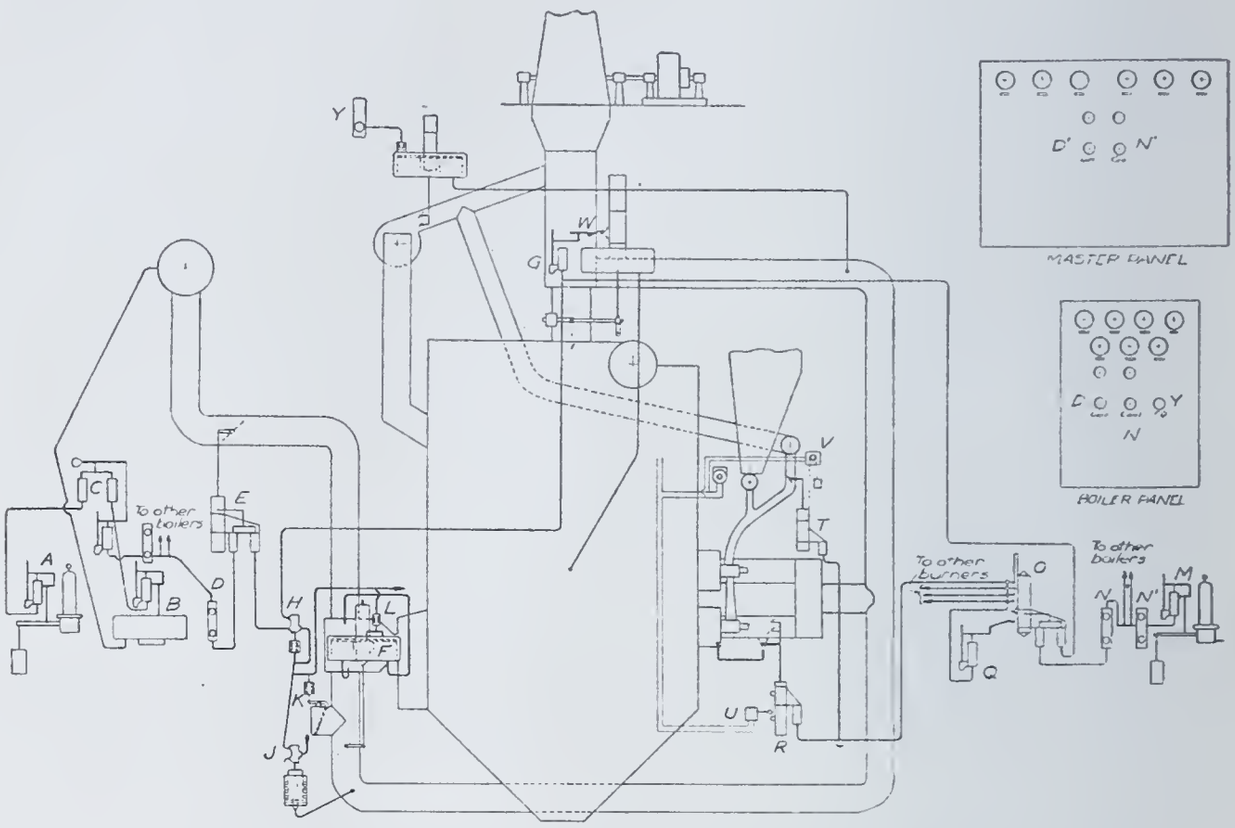

Fig. 8. Combustion Control Applied to Steel-Plant Boiler, Fired with Blast-Furnace Gas and Powdered Coal.

The methods described heretofore are applicable with only minor changes to central-station boiler plants of other types and to all the common auxiliaries. Considerable freedom of choice can be exercised as to details of equipment and manner of use. A far more difficult task is presented in specifying a suitable control system for combination fired boilers.

The very necessity for careful elaboration of design for these plants tends to lift automatic control out of the class of valuable adjuncts to boiler-plant economy into that of indispensability. Fig. 8

illustrates a type of design used in several plants burning both blast-furnace gas and powdered fuel under large boilers. It is doubtful whether such a plant, if devoid of automatic control equipment, could be operated indefinitely with entire success or safety.

In a plant burning both powdered coal and blast-furnace gas, the first and paramount requisite of control is safety. The automatic equipment must not only introduce no hazards of its own but must, in emergency, take all steps necessary to correct a dangerous condition arising from extraneous causes. The possible hazards are not merely the sum of those which may exist in burning either fuel separately, but rather a multiplication of the two. For example, the loss of an induced-draft fan requires prompt action with either pulverized fuel or blast-furnace gas. In combination firing, where either fuel alone can develop full boiler output, the fan is usually adequate only to handle the products of combustion of the blast-furnace gas. After casting, or when for other reasons the volume of available gas fuel is small, and the boilers are therefore operating on coal at full capacity, sudden restoration of the gas supply can quickly overload the fan and cause an efflux of carbon monoxid from the furnace. The condition is analogous to the loss of the fan, but occurs despite perfect operation of the latter.

While electric power in the modern steel plant is thoroughly reliable, attention must be given to the possibility of failure. Should power fail, motor-driven fans will stop, and possibly coal-feeding equipment as well. The supply of blast-furnace gas will continue. Under this condition it becomes desirable to lock out the coal feeders, to open the stack damper to provide maximum natural draft, to open natural-draft air inlets to gas-burners, and to block off all forced-draft ducts to prevent accumulation of gas therein and reduce the rate of admission of gas to that which can be burned with the draft available. These steps once taken in proper order, the equipment should be so locked in position as to require manual release in safe order upon restoration of power.

All these operations should be performed before the control equipment ceases to function, if it is dependent on electrical power. One way of accomplishing this is by the use of compressed air and the provision of receiver tanks of adequate capacity. It then is possible to arrange for several minutes of normal operation of the control

(even though the control power fail temporarily), followed by a gradual adjustment of the controlled equipment towards its open or closed position before the air supply fails completely. While pneumatic equipment can easily be designed to maintain its previous setting upon failure of air, this would be an unsatisfactory and occasionally dangerous feature. To lock any boiler auxiliary or damper at a fixed setting is extremely undesirable in the face of a fluctuating load and an independently and rapidly fluctuating supply of blast-furnace gas. Equipment is therefore so arranged that upon continued failure of electrical power, each auxiliary will be brought to that end of its range which is safer, or which will cause the maximum steam-generating rate.

The second requirement of automatic combustion control for combination fired boilers is maintenance of suitably constant steam pressure. This presents no unusual feature except that sequential admission of two fuels must be accomplished without undue deviation of steam pressure.

Another requirement is that of furnace draft control. While somewhat larger variations of furnace draft are considered admissible in combination fired boilers than with pulverized fuel alone, a positive furnace pressure is quite undesirable, and excessive draft is almost equally so. Equipment capable of maintaining atmospheric pressure, $\pm$ 0.01 inch in stoker-fired boilers, is quite commonly adjusted on combination fired boilers to maintain — 0.20 inch $\pm$ 0.05 inch.

The furnace draft control must usually be accomplished by control of stack draft. The volume of exit gases per B.t.u., or per cubic foot of air, is different for pulverized fuel and blast-furnace gas. There is therefore no correlation between uptake draft and any other single variable determining combustion rate. The uptake draft must be adjusted to the demands of the furnace despite wide variations in pressure drop through the boiler passages.

Air-fuel ratios from the standpoint of control are at present most simply maintained by providing separate air controlling means for each fuel, functioning in accordance with the supply of each. If otherwise arranged, complex control is necessary to permit simultaneous burning of both fuels at high economy. Maximum economy is just as necessary with both fuels as with powdered coal alone, ex-

cept perhaps when an excess of gas is available, as inefficient utilization of gas increases consumption of coal.

The boiler shown in Fig. 8 is equipped with two Steinbart burners for blast-furnace gas and four burners and feeders for pulverized fuel. The coal feeders are driven by adjustable speed (500—2000 r.p.m.) direct-current motors. Each feeder motor has a complete starting panel and separate field rheostat.

There are two motor-driven forced-draft fans and two motor-driven induced-draft fans. The motors are of the multi-speed, wound-rotor type controlled by pilot-motor operated drum switches. One induced-draft fan and one forced-draft fan are energized from one power source; the other pair from a second independent power source.

The primary control is from steam header pressure. Gas is admitted to the boilers in accordance with steam pressure variations so long as the amount of gas called for does not reduce the pressure in the incoming gas main below a predetermined amount necessary for other mill operations. Should this occur, the control of gas is automatically transferred to what in effect is a bleeder control on the gas main, permitting only that quantity of gas to go to the boilers which can be taken without further reducing the gas main pressure. Upon an increase in gas supply the control is transferred back to steam pressure.

If the supply of gas is inadequate to carry the steam load, the steam pressure drops to a lower range and powdered coal is automatically cut in. Burners are started in sequence at one-half capacity until all are in service, after which they are brought simultaneously to maximum rating.

In Fig. 8, A is the master gas controller for all boilers. It responds to steam pressure and originates a pneumatic impulse varying therewith. B is the gas-pressure regulator, which does not operate as long as the gas pressure is up. The impulse from A is transmitted unchanged by the dual relay C and determines the gas supply to the boilers unless the gas pressure drops. If this happens, regulator B becomes operative and sets up an impulse which takes command of dual relay C in order to maintain the gas pressure. From C, the impulse passes through a manual control device D^1 and then branches to the individual boilers.

A, B, and C are mounted at a centrally located master panel which also carries the master coal controller M, and its associated manual control relay N^1. Subsidiary manual control relays for gas and coal are located at each boiler on individual boiler panels. These relays may also be used for modifying the normal load distribution between boilers.

The gas regulator E takes its actuating impulse from the boiler relay D and operates the 54-inch gas damper either to hold the correct steam pressure, or to maintain adequate gas pressure. This regulator can also be operated in response to an emergency impulse in case of failure of either forced or induced draft. If either fan fails, the 54-inch damper is closed to a minimum position which will just admit the amount of gas that can be burned with natural draft. The normally varying quantity of gas passing the damper is admitted to Steinbart burners. Individual regulators for each burner control the forced-draft air supply to balance air flow against gas flow.

In case the gas supply is deficient, coal regulator O at each boiler is actuated by the impulse from boiler relay N. As the steam pressure drops through the coal regulating range, this regulator opens one after the other of switching valves P. Each of these valves communicates with a group of two subsidiary regulators for one burner, and admits to them an impulse which carries them through a portion of their stroke. The extent of this initial movement, common to all eight regulators, is determined by the adjustment of unit Q. After all subsidiary regulators have been opened to Q through the switching valves, regulator O picks up the operating arm of Q and thereby can advance all eight subsidiary regulators to their own position, if required.

R and T are shown as one of the four pairs of burner regulators. R operates the secondary air dampers and burner vanes; T, the primary air damper and the coal-feeder rheostat. In addition, R energizes the starting panel of the feeder motor as soon as it leaves the "closed" position.

Inasmuch as the pressure of secondary air up stream from the regulating damper is held constant, and the vane positions and feeder speeds bear a fixed relation to impulse magnitude, the air-fuel ratio is a function of the relative strokes of R and T. These strokes are calibrated to each other by adjustable compensating devices.

Constant secondary air pressure is maintained by regulator X.

The magnitude of the air pressure can be altered by adjustment of relay Y which is located at the boiler panel. An adjustment of air-coal ratio is thereby available. X is equipped with contacts (not shown) which actuate the motor-speed drum switches, and thereby change the speed of the forced-draft fan as required.

The furnace draft controls the position of the uptake damper and the speed of the induced-draft fans through regulator W. Starting with the regulator in its lowest position and the uptake damper at the minimum opening, increasing furnace pressure allows the damper to open. As it reaches a predetermined position a switch (not shown) is closed, actuating the motor drum switches to increase the speed of the induced-draft fans. A similar switch is provided, operative on reverse movements, for decreasing the speed of the fans.

If, with motors at full speed, the wide open damper will not relieve the furnace pressure, further upward movement of W takes place and relay G is picked up. G sets up an impulse the first effect of which is to cut back on regulator O and incrementally reduce the coal feed and its air supply. If this does not relieve the increased furnace pressure (as may happen upon failure of one or both fans) the impulse from G reaches a magnitude which will actuate the gas control of the boiler. The impulse from G passes through H and closes regulator E and its associated gas damper. If closed in this manner, the gas damper is permitted to open and the coal is readmitted, both gradually, when the furnace draft is restored to its customary value.

This completes the description of what may be called "normal operation" of the control. A number of additional interlocks, relays and safeguards, some of which will be described, take care of emergency conditions.

Electrical interlocks supplied by the motor control manufacturer drop out one forced-draft fan upon failure of one induced-draft fan. Simultaneously a louver damper is closed in the inlet of the failed fan. If the second fan fails, the second forced-draft fan is dropped, and the louver damper on the induced-draft fan opens to give the maximum natural draft. Either forced-draft fan may be interlocked with either induced-draft fan. If the direct-current supply fails, the coal feeders can not be started automatically until a "no-voltage" relay is manually reset.

The coal feeders can not be started until a positive pressure of forced draft is available. This is assured by the operation of safety check J, which upon failure of forced draft actuates a switch (not shown) which breaks the control circuit to the feeder motors. Such a failure, whether resulting from stoppage of forced-draft fans alone, or of all fans, likewise causes operation of regulator E to close the gas damper; of air-gas regulator F to close the air damper; and of latches K to open the natural-draft air inlet doors to the burners. A manual release is required before normal operation is restored, and means are provided to prevent admission of gas to the burner before the natural-draft air doors have been closed and the forced-draft air dampers opened.

The interlocks and relays are of more than academic interest. They comprise a real and effective safeguard to the operators. Their condition is inspected weekly. The weekly inspection consists in choosing a time at which the boiler is operating on both coal and gas, and then in abruptly de-energizing both induced-draft fans. Provided all relays and interlocks have functioned properly and the rating has been reduced to that possible under natural draft, the boiler is again placed in operation manually. The whole operation requires but a minute or so. During this period the remaining boilers have picked up the load and carried it without material change in steam pressure.

In designing a control system of this nature, the manufacturer can not restrict himself either to standardized apparatus or to standardized theories. Where a complicated function is to be performed, a suitable regulator must be designed. Where two or more quantities are to be proportioned there is often no choice of methods to be used as is the case in simpler installations. The circumstances may require the use of speed-responsive, flow-responsive, or pressure-responsive means, or of devices for continuously reproducing an adjustment the magnitude of which has been determined by experiment for each rating. Sometimes a combination of two or more of these must be employed. Whichever plan of control is enforced by circumstances, the equipment for its execution must be suited to the service, and capable of rapid, stable, accurate, and continuous operation.

The fitness of each piece of equipment for its intended use is of more importance here (as elsewhere) than the consistency with which its application follows the teachings of one particular theory or another.

DISCUSSION

C. L. Dudley:* The subject of automatic control has been presented to us by four very able representatives of the leading control manufacturers of the country. They have told us what should be controlled, and how it should be done. They have offered us a solution of our problems and I am sure that the great majority of their hearers agree with them, at least in a general way; but none of us may travel about the country, visiting power-plants, both large and small, without encountering many operating engineers who are disappointed with the results of automatic control, which they have purchased, installed, and attempted to operate, only to abandon it after it had failed to do what was expected of it.

It is quite probable, that, in the power-plants operated by these disappointed engineers, you may find equipment supplied by the very firms whose representatives have talked to us to-day. Now it is not our thought to criticize any control manufacturer for the failure of the aforementioned equipment. We do not believe the fault lies with the equipment in the majority of cases; but we do believe that the manufacturer's sales engineer has a responsibility which is often neglected especially in isolated plants, where the value of the equipment does not seem to warrant continuous contact.

We believe that the sales engineer should insist that his erection and service engineers establish an intimate contact with the operator, whose responsibility the apparatus is to become, and the smaller the plant or the more remote its location, the better this contact should be. The service man should not leave a new installation until the operator is thoroughly conversant with the entire equipment, as to its purpose, its care, and its maintenance. An extra day or two may save the reputation of this apparatus, in this plant and among local potential users of automatic control.

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An occasional caller, in the person of a service engineer, is almost always welcome. A new man may have superseded the old operator and he may desire information concerning a strange device. Without the desired information, the equipment may be abandoned when it goes wrong, and they all go wrong occasionally; while, if the operator is fully informed concerning his control apparatus, he may wish to extend it. Also, we believe the sales engineer is too prone to talk of the rugged construction of his equipment, neglecting to impress the prospective purchaser with the need of continual watchfulness and care after installation. The result is that, often unconsciously, the purchaser gets the impression that little or nothing can happen to this particular device, and he is grievously disappointed when he sees black smoke pouring out of the stack, or finds his plant idle because of trouble with his steam control.

The sales engineer generally is in touch with the plant manager or his chief engineer, to whom his explanation is perfectly clear; but, after purchasing and installing the equipment, the busy chief engineer turns the appliance over to a combined fireman and water tender with the remark that "there is a gadget that will help you to save fuel." This is where the erector and service men should and will function, if they desire good results for either or both the seller and the buyer.

Another source of discouragement to the purchaser—and one that lies, at least to a large extent, with the sales engineer—is the readiness with which the latter promises to control, absolutely, any element in the system. These promises are often made without a thorough knowledge of operating conditions, and when the control fails to function as he expected, the purchaser is disappointed, and finds that he must spend more money to correct or control some unexpected element that both the purchaser and the sales engineer had overlooked. This is less excusable in the sales engineer than in the purchaser, for he knows how important it is that all appertaining elements be in accord, if his control is to function properly. Hence we believe it is the duty of the control company's representatives to investigate each element that may affect the correct operation of the device he proposes to furnish.

Larger plants are generally equipped with a plant efficiency engineer, who is interested in getting the maximum value from all equipment. In such plants, control devices are generally successful; these

engineers will see that their subordinates are properly educated in the use and care of any new equipment installed. These same engineers will generally understand the apparatus they are buying, and be careful to neglect no feature that may later cause trouble.

We have intimate knowledge of an industrial power-plant which recently installed new steam-generating equipment to co-ordinate with the best of the old plant and to replace the remainder. The load on this plant is subject to radical and frequent changes. The main fuel is a by-product of the plant and varies in quantity and quality, frequently being insufficient to meet the demands for steam, hence the new boiler plant had to be built in such a way as to utilize pulverized coal as an emergency fuel. The old boiler house that must co-ordinate with the new plant can use only the by-product fuel. It must also be noted that the new boiler plant is much more efficient than the old plant, hence the new plant must be operated at high ratings at all times, while the old boiler plant will act as a make-up when steam demands are above average. Also the new plant is a system at moderately high pressure, with a total temperature of 700 degrees F., while the old plant is a system with lower pressure and lower temperature. The two plants are connected through a pressure-reducing and desuperheating system. The old boilers can never meet the full demand for low-pressure steam, hence there must be a flow from the high pressure system to the low-pressure system. The consumers on the high-pressure system make it necessary to protect this system from too much drainage as well as protect the low-pressure system against too much pressure.

It will be understood that, in order to utilize the by-product fuel to its fullest extent and at the same time operate with the greatest overall plant efficiency, it is necessary that the proportion of the by-product fuel between the two houses must be constantly changing, and the emergency fuel regulated in the new boiler house to keep its output constant. If a decrease in load causes the by-product fuel to be more than sufficient to meet the steam demand, the excess must be wasted after the emergency fuel has been entirely cut off. Since the new boiler plant is equipped with adjustable-speed, motor-driven auxiliaries, it is necessary to cut off all fuel and forced draft air in case of electric power interruption to one or more of the motor-driven fans. The boiler must be automatically made ready for natural draft opera-

tion at lower rating. Draft control is a combination of damper and fan speed adjustment.

With the foregoing items before us, you may see that the control of steam, fuel, and combustion is rather extensive, costing about $100,000 installed.

When ready to obtain proposals on the automatic control of this steam plant, sales engineers from all of the companies whose representatives have talked to us to-day, were called in, and it is significant that in all cases the line of thought presented was the exceptional simplicity and ruggedness of construction in each particular make of control. Only one sales engineer made any effort to warn the prospective purchaser that such an extensive and complicated control should have some one in charge who thoroughly understood the purpose, operation, and maintenance of the system installed. Since this was in line with the steam engineer's experience, he discussed this phase of the subject with the successful bidder.

When ready for erection, the steam engineer with the help of the control manufacturer's engineer, selected a young man to assist the erection engineer, and to study the device from start to finish under the service engineer. The management has been very well satisfied with the result, and, since the installation, whenever the control company's service engineer has been in the plant and inspected the equipment he drops into the steam engineer's office to discuss the performance of the apparatus and is asked to offer his comments concerning the operator's ability. The operator is privileged to call the control company's service engineer at any time to discuss any question of operation or maintenance that may arise. In this way full cooperation between plant owner and control manufacturer has resulted in a very satisfactory job.

This boiler plant was put into operation some weeks before the control equipment was ready. During this time, the various elements were controlled by hand, and the experience during these few weeks furnished all the argument needed to convince all concerned of the value of automatic steam plant control.

When the service engineer informed the overworked and worried operators that he was ready to take over the control of the plant, he was greeted with a great sigh of relief.

Everybody, from the boiler superintendent down to the ash man, is so thoroughly sold on the automatic control, that the man in charge of the control equipment might better be in jail than neglect the control devices.

M. F. Béhar:* With your permission, Mr. Chairman, and with the indulgence of my fellow members, I shall discuss not the last paper but all four,† not so much their content as their import, and not only the papers but statements made in the discussions this afternoon and evening. This meeting bids fair to rank as historic for it is the first meeting held under the auspices of two engineering organizations and devoted entirely to automatic combustion control. We have heard four representatives ably expound each his company's solution and we have seen on the screen four different combustion control systems. I should say five, because Mr. Boynton, who came from Chicago to participate in this meeting, exhibited slides of his system. As a matter of fact there are on the market four times five combustion control systems some "complete" and some "incomplete", some fully automatic, some semi-automatic and some deserving the label "manual", some electrically operated, some employing fluid relays (pneumatic or hydraulic), and some incorporating both electrical and mechanical power devices.

With some twenty firms engaged in the development and installation of such systems, combustion control may be said to constitute an industry. With this large gathering of representative technicians devoting two sessions to its consideration, *automatic* combustion control may now be said to rank as an important branch of power-plant engineering. Can it be said, then, that the day of automatic combustion control has arrived? I, for one, think that it has. And yet, gentlemen, we have heard distinguished power-plant engineers assert emphatically that it has not.

If what they have in mind is the relatively small proportion of steam plants equipped with complete and fully automatic combustion control systems, they are right and we all agree.

But some skeptics declare, in effect, that automatic combustion control isn't here because the systems developed up to now haven't

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†Other papers at same meeting by C. J. King; E. S. Bristol and B. F. Keene; and H. M. Hammond.

worked, don't work, and can't work. On the other side we hear evidence of the continuous, automatic operation of various systems. The statements seem to be diametrically opposite.

Inasmuch as the advocates of both sides are truthful men and inasmuch as they use the same expressions, the inference is that they attach different meanings to identical terms. It seems to me, after years of specialization in automatic devices, that several languages, all made up of English words, are being used in this field of engineering. The four papers, if I may say so, were written in four different languages. Here are some of the terms heard to-day that undergo changes of meaning:

"Impulse," "quantity," "factor," "condition," "performance," "deviation," "functioning," "lag," "streamline flow," "setting," "setting point," "position" (as adjective), "adjustment," "readjustment," "demand," "supply," "capacity," "rate," "rating," "characteristic," "characteristic curve," "range," "calibrate," "normal," "standard," "transform," "transfer," "transmit," "translate," "response," "reaction," "measuring," "metering," "relay," "medium," "flexibility," "sensitivity," "anticipatory" and lastly, those long-abused words—"accuracy" and "precision."

Yes, there are groups of earnest, competent engineers in Pittsburgh, Philadelphia, Cleveland, Rochester, Brooklyn, Waterbury, Foxboro, New York, Chicago, Schenectady and other centers of instrumentation, whose group languages all differ from one another.

If it were not so serious a matter, it would be amusing in the extreme, this modern Tower of Babel. I can not resist mentioning that when one of the companies here represented recently hired a competent designer of automatic systems from another company, he could not make himself understood and could not understand his new associates. A foreigner? Oh, no! But he had worked on electrical systems and his new employers specialize in non-electrical systems. Two groups of combustion control engineers are separated by an idiomatic barrier which in this case proved insurmountable.

A single *"duty regulator"* made in Rochester, N. Y., is identical with a single *"system controller"* made in Brooklyn, N. Y., in that they are composed of exactly corresponding elements, differing only in details. A "prospect" innocently referred to the latter as the for-

mer while conversing with a loyal sales engineer employed by the Brooklyn firm, and an eloquent sales talk was suddenly punctuated by a display of intense emotion. I almost said "uncontrolled" emotion. Had I the time, I could relate many such tragi-comic incidents, or else could ask this audience of engineers kindly to write down definitions of some of the terms I recited a while back, not the dictionary meanings but the specific definitions pertaining to the art of automatic control. In every case, I am certain that the collected slips could be divided into at least two distinct "schools." In the case of "sensitivity" I know from having talked with many of you that three widely different definitions would each be handed in by several advocates.

Mind you, I am not laying blame on any one, least of all on the companies so ably represented here, which have designed modern combustion control systems. Loose terminology mars most of the papers on this and on the other branches of instrumentation and the reason is that most American inventors and engineers are practical men—men of action, not of words. Practice is so far ahead of theory that throughout all these years of ingenious developments the principal terms and basic general principles of instrument control technology had never been formulated, had never appeared in print until a few months ago. I make this categoric assertion, my friends, after several years of research on this subject, in the course of which I came across the writings of German and other engineers who not only designed automatic control systems but ably discussed their principles and wrote down impressive series of differential equations. And this *sui generis* text that came out a few months ago is only a pitifully meager beginning. It must and will be expanded because, gentlemen, not only is this field of engineering of ever increasing importance, but its growing usefulness depends largely upon its formulation, upon its transformation from an art practised by unassociated groups of technicians into an exact science, and upon the universal acceptance of this formulation among both makers and users of automatic controllers.

The first thing we need is an authoritative and widely read set of definitions. Wherefore I repeat that this meeting bids fair to rank as historic. Being a joint meeting, it may mark the beginning of concerted efforts wherein the Engineers' Society of Western Pennsylvania, the American Society of Mechanical Engineers, and the in-

strument manufacturers will be joined by other societies and other commercial organizations. The movement should not be restricted to automatic combustion control, which is but one branch of instrumental control technology, nor can its scope be limited to automatic control, for one of the cardinal principles of instrumentation is that *before a condition can be controlled it must be measured.*

Every automatic controller *must* comprise a primary device in the nature of a "measuring instrument" or "meter." Every automatic combustion control system *must* start with primary elements not only *responding to changes* in steam pressure, in draft, or in CO_2 content, or in some other selected condition, but responding to the values of these conditions; that is to say, "measuring" or "metering" these conditions. *Every* automatic combustion control system, therefore, could be proved to be a "metered control" system. We have heard, however, that the term "metered control" should apply only to systems embodying at least one measuring element responding to the *time rate of change* in the values of a measured condition, and capable of reversing the direction of the corrective action *before* the measured and controlled condition has been restored to "standard." I heartily agree with the underlying idea, but I question the adequacy of the terms coined to express it.

First measurement then control. Wider appreciation of this principle, by the way, would soften and reduce the number of expressions of invidious distinctions made by some critics—some blunt and caustic critics of automatic devices and some restrained critics of the other fellow's devices.

Some participants in the discussions drew the inevitable comparisons between human brains and mechanical brains to the detriment of the latter. To say that such talk is beside the point would be an unforgivable impertinence in view of the high standing and rich experience of the engineers who uttered these remarks. I welcome, however, the opportunity thus afforded me to declare that this proves the defectiveness of the terminology which engineers are forced to employ in discussing automatic devices. May I suggest that universal use of the expression "instrumental control" would avoid such misunderstandings?

You all know that instruments can measure various magnitudes with an exquisite precision far beyond human powers—linear magni-

tudes to the millionth of an inch; temperature to a degree or two in the plant and to the thousandth of a degree in the laboratory; frequency to plus or minus one-thousandth of one per cent. of the instantaneous value; current to the milliampere; capacity to the microfarad, and so on. An automatic controller, my friends, is a measuring device hooked up to a corrective mechanism. As Archimedes said that given an adequate lever he would move the earth, I say, give me an adequately sensitive primary system and an appropriate power device and I'll control automatically any variable you may name. In fact I'll not be the one to control it; the instrument will do it while I placidly play a round of contract at the rooms of the Society downstairs. Of course we all know that a rational human being can do things that no control mechanism can possibly do. The simplest illustration is driving a car. When you see a hill ahead, you step on the accelerator in order to anticipate the increased load on the engine. Such an anticipatory feature is not yet available for road vehicles, but some control instruments in the power field perform analogous functions. The Bailey Meter Company has shown us an anticipatory feature of that nature. Sudden increase in the load, instead of manifesting itself in a lowering of the water-level in the drum, does the opposite by reason of the increased steaming and greater swelling as Mr. Dickey has shown. By recognizing that particular factor, the Bailey feed-water control system can be said to exercise human intelligence, and certainly no human being could so correlate his visual inspection of a steam-flow meter and of a water-level sight glass and of a pressure-gage, and adjust the feed-water rate in accordance with the integrated result of those three simultaneous observations.

But in order to bring about a widespread understanding of the underlying principles of a science, these must be formulated in a language intelligible to all groups concerned. Are we then faced with a vicious circle? Not at all, for the immediate task ahead of us does not involve teaching anything new and unprecedented; it is merely a matter of agreeing, of selecting and of adopting.

For example a "direct acting" fluid relay controller, according to some manufacturers of this class of instruments, is one which increases the supply of controlled medium when the value of the controlled condition increases; while according to other manufacturers it is one which does exactly the opposite. Similary with control

valves; a "direct acting" valve is one which opens, or which closes, on failure of auxiliary power, depending on what manufacturer's booklet you happen to be reading. Let the American Society of Mechanical Engineers and the American Standards Association decide, and this particular source of confusion will be ended, without hurt feelings on the part of any one. In almost every case the adoption of a standard definition will require little time and effort.

A requisite for the attainment of automatic control is what may be called "controllability." In recent years there has been great progress on the part of manufacturers of furnaces, stills, autoclaves, etc., to make their equipment controllable in order to make it possible for automatic control instruments to eliminate variables and obtain better results. But the manufacturers of steam-generating equipment and auxiliaries have failed to make their equipment adequately controllable. No better testimony in support of this contention can be adduced than the four papers that were read here, in each of which there were concrete instances of an almost impossible state, where it was almost impossible to control the variables. On the other hand we heard evidence of efforts toward better "controllability," as when Mr. Griffin said that a stoker drive and other auxiliaries had deliberately been redesigned with "better control characteristics." When boilers and auxiliaries will be controllable, automatic combustion control systems will "work" to the satisfaction of every one.

D. L. McNulty, *Chairman:** Mr. Béhar's indictment of the engineer and his vocabulary may be somewhat deserved. Some engineers, at least, do not use the proper terminology. But I would like to point out to Mr. Béhar that we have used a screen and stereopticon to assist the speakers so I think most of the engineers understood what was going on.

Mr. Béhar also mentioned the fact that the boiler manufacturers should be indicted because their equipment is not controllable. Yet the most of their devices are about as controllable as human nature, with which all of us are always dealing.

No one has yet brought out any figures on the initial cost of any of this equipment. I have no actual figures that I care to publish; but, in connection with the installation just mentioned, our records

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show that 45 per cent. of its total initial cost was for the equipment proper and the services of the manufacturers' representatives, while 55 per cent. was for miscellaneous materials (conduit, wire, etc.) and labor of installation. In other words, the equipment proper represented less than half the cost of the total job in that particular case.

G. W. Smith: Mr. Dudley has touched upon a very important feature of the sale and use of combustion control equipment. The control manufacturer should render occasional service during the first year or two of operation, not so much because the equipment may require it, as because the operators must be made completely independent in its use and adjustment.

Mr. Béhar has commented on the desirability of having controllable equipment to which to apply control; on the lack of uniform nomenclature in to-day's papers; and on the complexity of their subject matter. As to the first of these, I am safe in saying that the great majority of the problems coming across the control engineer's desk relate not to choice of control apparatus or methods for a given application, but to adapting standard apparatus to multitudinous boiler auxiliaries of different types and different degrees of control.

It is possible that designers of control equipment have been too busy developing and applying control equipment to worry about the niceties of nomenclature. Certainly there is no uniformity here. What is known as "spring scale," or simply "scale" to one manufacturer, is called "gradient" by another, and "compensation" by a third. Similar instances may be multiplied. If Mr. Béhar or his organization can produce a terminology accepted by all parties interested, he will have accomplished two things—he will have produced uniformity where only inconsistency and contradiction now prevail, and he will have brought the manufacturers of control equipment to one form of agreement.

I don't believe we may classify the papers delivered here to-day as complex. After all, they have dealt with applications of control rather than regulator theory. In comparison with what may be written about the latter, our papers were in fact quite elementary. Few papers, and fewer books, have been written in English on theory of control. Non-linear differential equations of the fifth and higher

orders are required to define accurately the regulating action of a pressure controller.

So much has been said to-day about the absence of intelligence in a regulator, and about the regulator possessing only the brains with which it was designed and adjusted, that we may safely conclude that when a control installation exhibits dementia, it is reflecting an unusual adjustment, or an inherent defect.

Mr. Thomas and others have spoken of the impossibility of incorporating the "anticipatory function" in automatic equipment. This may in some cases constitute a valid argument against certain types of installation. In others, it appears to me that what is criticized is not failure to anticipate, but failure to function with rapidity. Prompt and speedy automatic control may often surpass the best manual control, apparent admissions to the contrary notwithstanding.

I have in mind a large power-station in southern West Virginia which supplies power for electric locomotives in mountain service. The load fluctuations are severe, the load varying, for example, from 8000 to 21,000 kilowatts in less than 60 seconds. When operated manually, all manual controls were connected mechanically to one hand lever. An operator was stationed at this lever and provided with a load indicator on the outgoing buses. At the first intimation of load change this operator was supposed to throw all equipment towards the extreme of its range in anticipation of the impending change in steam pressure. Poor fuel economy and very unsatisfactory pressure regulation resulted.

Installation of a combustion control system having speed with stability, and taking its impulse from header pressure, led to improved economy and much improved maintenance of pressure. In this case, no doubt is possible of the superiority of automatic over the best hand control.

M. F. Béhar: I was hoping that some other speaker from the floor would ask one of these four speakers to discuss the relative advantages and limitations of the electric and of the fluid relay classes of controllers. The statement is sometimes made, "We are willing to consider an electric control system, but not a pneumatic or hydraulic, because the piping all over the lot will give us trouble." Have you any information on this question?

G. W. Smith: I thank you for the opportunity to answer that question. I can recall but one complete failure of air power in many years. In this case a derailed locomotive crane tore down the compressed-air supply line to a large boiler house. Even a failure of this type can be overcome by the installation of adequate receivers in the boiler house itself.

As to the difference between pneumatic and electric control and their relative advantages and disadvantages, I am of the opinion that a detailed competitive discussion has no place here. We have very definite beliefs on the subject. Repetitive operations through a limited number of discrete positions may often lend themselves elegantly to electrical means. Stable automatic control through a continuous range is another matter.

We consider it significant that the world's largest manufacturers of steam-turbines, who are likewise the largest manufacturers of electrical equipment in the world, always use hydraulic turbine control. Even where remote control of speed is desired, as with frequency control, the electrical devices used are not primary regulators, but are designed to influence or readjust the hydraulic governor on which final dependence is placed.

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